

Loading and performance of the support leg at different
approach speeds in Australian Football kicking

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Abstract

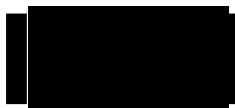
The support leg is a key part of kicking technique in Australian Football (AF) as well as soccer. Support leg mechanics have been found to be important for both distance and accuracy in male kicking from short run-ups. The next step in examining the involvement of support leg mechanics during fast approach kicks is an important direction to take given many kicks in AF are performed at moderate to high speed. There is also a need to extend this work to female kickers as well as males to determine if gender-based differences exist as this would mean different conditioning and development practices are needed. Therefore, this study aims to continue building on understanding the importance of the support leg in kicking in both males and females, and to understand the differences in support leg mechanics when athletes are moving at different speeds prior to the kick. A total of 19 males and 17 females, ranging in skill from high level local competitions through to the top professional leagues performed five kicks using a slow run-up (2-3m), and five kicks with a fast run-up (10-15m) towards a target approximately 35m away. All kicks were recorded using 3D motion tracking, sampling at 200 Hz and 3D force, sampling at 1000 Hz. Discrete data was determined at support foot touchdown and at ball contact, with maximum/minimum values were used between these events for knee and hip angles and angular velocities and for vertical and anterior-posterior (braking) forces. Continuous data was also evaluated from support foot touchdown through to ball contact for the same parameters. A mixed design ANOVA found that, males and females were significantly different in two of 11 discrete time measures: knee angle at ball contact with females having a more extended knee angle than males ($p = 0.009$) and hip angle at support foot touchdown with males remaining more extended at the hip than females ($p = 0.009$). A statistical parametric mapping mixed design ANOVA found there were significant differences between genders in sections for three continuous parameters: knee angular velocity, hip angle, and anterior-posterior ground reaction force (GRF). Fast and slow approach kicks were significantly different in all comparisons (11 discrete and six continuous parameters). The results indicate that males and females likely have similarities but also important differences in kicking techniques. There is also a clear need to train and coach both fast and slow approach kicks separately as the support leg mechanics were significantly different in all parameters, with GRF being higher. For strength training/injury prevention, the data suggests, there is a need to train knee extensor eccentric strength, eccentric and isometric quadriceps training, hip extensor strength and power as well as improving general hip and core strength. Future directions may be directed towards the kinetics of support leg mechanics, examining the kick leg at different approach speeds, and gender differences in the kick leg.

Student Declaration

I, Ryan Metz, declare that the 'Master of Applied Research thesis entitled Loading and Performance of the support leg at different approach speeds in Australian Football kicking' is no more than 50,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

I have conducted my research in alignment with the Australian Code for the Responsible Conduct of Research and Victoria University's Higher Degree by Research Policy and Procedures.

Signature:



Date: 14/01/2026

Ethics Declaration

All research procedures reported in the thesis were approved by the Victoria University Human Research Ethics Committee - HRE24-093

Signature:



Date: 14/01/2026

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List of Abbreviations

3D – Three dimensional

AF – Australian Football

AFL – Australian Football League

AFLW – Australian Football League Women's

AP – Anterior-Posterior Force

ASIS – Anterior Superior Iliac Spine

BC – Ball Contact

BW – Body Weight

CoM – Centre of Mass

GFR – Ground Reaction Forces

HAng – Hip Angle

HAngVel – Hip Angular Velocity

Kang – Knee Angle

KAngVel – Knee Angular Velocity

Max – Maximum

Min - Minimum

PSIS – Posterior Superior Iliac Spine

SD – Standard Deviation

SFTD – Support Foot Touchdown

List of Parameter Names

KAngSFTD – Knee Angle at Support Foot Touchdown

KAngBC – Knee Angle at Ball Contact

KAngMin – Knee Angle Minimum

KAngVelSFTD – Knee Angular Velocity at Support Foot Touchdown

KAngVelBC – Knee Angular Velocity at Ball Contact

KAngVelMin – Knee Angular Velocity Minimum

KAngVelMax – Knee Angular Velocity Maximum

HAngSFTD – Hip Angle at Support Foot Touchdown

HAngBC – Hip Angle at Ball contact

HAngVelSFTD – Hip Angular Velocity at Support Foot Touchdown

HAngVelBC – Hip Angular Velocity at Ball Contact

HAngVelMax- Hip Angular Velocity Maximum

HAngVelMin – Hip Angular Velocity Minimum

AP GRF BC – Anterior-Posterior Ground Reaction Forces at Ball Contact

AP GRF Max – Anterior-Posterior Ground Reaction Forces Maximum

Vertical GRF BC – Vertical Ground Reaction Forces at Ball Contact

Vertical GRF Max – Vertical Ground Reaction Forces Maximum

1.0 Introduction:

Australian Football is played on a field with an average length of 150m, requires teams to move the ball at great lengths to be able to score. The most proficient way of achieving this is through kicking, which is a key contributor towards team success (Robertson et al., 2016) as it's the only way to score a goal. It has also been reported that to kick proficiently can be a tactical advantage (Ball, 2008). Proficient kicking can be defined as being able to kick accurately and for distance.

The kicking phase can be broken down into several different phases, including kick leg toe off, support leg land, and ball contact (Figure 1, (Blair, 2019)), where numerous technical components are able to influence the outcome and distance of the kick (Ball, 2008). Understanding the key technical components within the kicking phase can help shape the creation of an 'optimal' kicking technique. Being able to understand the key components during the kicking phase is important for both males and females as it can help enhance player performance, whilst being able to understand what occurs when athletes move at different speeds prior to kicking can help scenario-based coaching and help enhance research-based conditioning training.

During the 2025 AFL season, across all teams, the average kicks per game was 207.9, with the highest team averaging 232.1 kicks per game, and the lowest team average at 184 kicks per game (Australian Football League, 2025c; Champion Data). For the 2025 AFLW season, the average across the league was 150.5 kicks per game, with the highest team averaging 178.5 kicks per game, and lowest averaging 138.8 kicks per game (Australian Football League, 2025b; Champion Data). The highest averaging AFL players complete approximately 20 kicks per game, whilst the highest averaging AFLW players complete over 15 kicks per game (Australian Football League,



Figure 1: Kicking phases

Taken from: Blair, S. (2019). *Biomechanical Considerations in Goal- Kicking Accuracy: Application of an Inertial Measurement System*

2025a, 2025b; Champion Data). This highlights the importance of being able to kick efficiently to be able to generate effective ball movement to help lead to team success. Across these large number of kicks per game, these kicks are performed in various situations during the game, where each kick would be completed in a slightly different scenario, with some kicks being completed on the run, whilst others could be from a standing start, or of a few steps, therefore it is important that kicking is studied under different conditions.

Match play demands in elite football have increased substantially over the past two decades, with players now required to perform high intensity running and movement at greater speeds more frequently. In 2009 it was found that players were moving at higher speeds more often than in 2003 (Burgess et al., 2012), and this has been supported by previous research where it was found that physical demands were higher in 2008 compared to 2005 (Wisbey et al., 2010). With players moving at higher speeds more often, it is important to understand how moving at such speeds is impacting player performance, specifically the kinetics and kinematics during kicking, with an emphasis on the support leg. Even though player movement speeds have increased over the last two decades, there are a mixture of kicks being performed, with some kicks being completed with fast approach speeds and others with a slow approach speed. Fast approach speed kicking typically occurs during dynamic match scenarios such as fast breaks or when players accelerate away from congestion, requiring the ball to be kicked while running. In contrast, slow approach speed kicking commonly occurs following a mark, during controlled ball movement in the backline, or when kicking from a short, constrained approach (e.g., 3–5 steps). These scenario-dependent kicks are yet to be examined to understand if approach speed prior to the kick influences the kicking phase mechanics and if there are any key differences during the kicking phase that may influence kicking outcomes.

Previous research highlights the critical role of the support leg in AF kicking performance, influencing both kick distance and accuracy. Ball (2013), demonstrated that a more extended support-leg knee at foot strike, reduced peak knee flexion, and shorter stance time were strongly associated with greater kick-leg foot speed. Ball (2013) reported large vertical and braking ground reaction forces that exceeded those reported in soccer. These kinematic and kinetic patterns suggest that a stiffer support leg may help maintain a higher kick leg hip position, enabling a longer lever and greater foot speed at ball contact. When examining kicking accuracy, Blair et al. (2020) reported that more accurate AFL goal-kickers exhibited a more extended support leg knee

at ball contact, whereas Dichiera et al. (2006) found greater knee flexion in more accurate short distance kicks leading to a conflict within kicking support leg literature. These differences may be partly explained by differences in approach speed and kick distance, as faster run ups and longer kicks appear to favour a more extended support leg to maximize foot speed. This literature suggests support leg mechanics may differ under differing tasks, with approach speed and kick distance as factors, highlighting the need for further research.

Approach speeds for previous AF research into support leg dynamics were specific to the kick task, but did not include fast approach speeds which are also performed in AF games. These speeds have been reported to be between 3.4 m/s (Ball, 2013) to 4.1 m/s (Blair et al., 2020) but higher running speeds of players have been reported of well over 5 m/s (Wisbey et al., 2010). Further, in soccer, biomechanical differences have been found when performing the same kick task but at different approach speeds (Augustus et al., 2017). There is clearly a need to understand what is happening when athletes are moving faster during kick execution in AF, and what adaptations players make. If there are adaptations, what training can be done to help improve player performance at these speeds? Additionally, what loads are present going through the support leg that has not been previously discovered?

Research from soccer and rugby has identified clear sex differences in both support leg and kick leg mechanics. In soccer, female players have been shown to produce significantly lower support leg knee joint torque and power during maximal instep kicks compared to males, limiting their ability to generate whole-body lift through knee extension (Iitake & Iwasaki, 2024). This may affect kick distance, as whole-body lift and a more extended support leg have been associated with longer kick leg lever lengths and greater foot speed (Ball, 2008). Similar findings have been reported in rugby place kicking, where females exhibited smaller support leg knee extensor moments and slower hip extension velocities following support foot contact, indicating a reduced ability to transfer momentum from the approach into the kick (Atack & Bezodis, 2023). As a result, females appeared to rely more heavily on forceful contraction of the kick leg hip flexors and knee extensors, a strategy previously linked to reduced kicking accuracy (Atack et al., 2019). Sex differences are also evident in kick-leg mechanics, with females achieving shorter predicted kick distances and lower ball and foot velocities across soccer and rugby (Atack & Bezodis, 2023; Boyne et al., 2024; Katis et al., 2015). Males demonstrated greater distal joint angular velocities, higher segmental energies, and more effective proximal-to-distal sequencing, leading to superior energy transfer and ball velocity (Boyne et al., 2024).

Only a small number of studies have examined kicking in elite female AF (AFLW), with the focus being on examining the kick leg. Research has primarily focused on AFL players, highlighting a clear need to understand what female kicking dynamics and support leg mechanics look like. This will allow for greater comparisons between males and females but also help create a baseline understanding of AFLW kicking dynamics, helping enhance the evidence-based coaching that can be performed to help player performance through coaching the ‘optimal’ kicking technique.

This study could benefit kicking performance in a number of ways: 1; It may help in informing coaching cues for different approach speeds (or if there are no differences then the same cues can be used), 2; It will directly inform conditioning components of kicking associated with the support leg in terms of speed and range of movement, 3; GRF data may help with improving conditioning programs for athletes to better handle the loads when moving at higher speeds potentially reducing the risk of injury, 4; Understanding the mechanism underlying the support leg function will provide a basis for biomechanical modelling which can inform future studies examining full body motion of the kick. Further, it has been found in soccer that the support leg was important in creating ideal conditions for the kick leg downswing at different speeds. Finally, the research will attempt to resolve the conflict on support leg knee flexion that exists in the AF kicking literature.

2.0 Aims

The focus of the research is to explore the importance of the support leg in kicking. To help understand this broad question, there are two sub-questions that will help the understanding of support leg mechanics in kicking.

1. Do support leg mechanics differ between male and female athletes in AF?

This will help to create an understanding if there is a need for different coaching cues for each gender.

2. Do support leg mechanics differ when kicking with different approach speeds in AF?

This will help to understand and quantify loads that go through the support leg for different approach speeds. It will help with understanding the different technical changes players may use when moving at different speeds, with longer and shorter ground contact times.

3.0 Literature Review

3.1 Background on kicking dynamics:

Kicking in AF is a complex movement, where every small detail can influence the kick, so understanding the dynamics is important. Australian football kicking can be broken down into six different phases, from kicking leg toe off through to the follow through (Ball, 2008), where there are many technical components that can influence the outcome, from the kick leg backswing, the ball drop, to ball contact. Understanding the key technical components during the kicking phase, will help create an understanding of what is important when analysing the kick when examining the impacts of the support leg.

Ball (2008), examining elite AFL players, found that foot speeds was a main contributor to kicking distance, where he discovered a moderate, positive correlation between foot speed and further distances ($r = 0.68$). Shank angular velocity was the next most strongly correlated parameter with distance (medium effect size $r = 0.31$), indicating that a larger shank angular velocity at ball contact was associated with greater distance. This is supported by previous literature, where a significantly larger shank angular velocity at ball contact was found for the long kicking group in juniors (Baker & Ball, 1996). A longer last step was another factor linked to greater kicking distance, as it may allow for greater hip extension and thigh range of motion, which in turn allows for the potential of greater foot speed development (Ball, 2008). The final factor found by Ball (2008), was the position of the ball relative to the foot and ground. The height of the ball at contact was correlated with distance, with larger kicks being associated with higher ball position. If the ball was too high, it would adversely affect the trajectory or if it were too far from the body, it would require “reaching” to kick.

Cust et al, (2019) reported the first biomechanical analysis on elite women’s Australian Rules football kicking ($n=15$), comparing preferred and non-preferred leg kicks. At ball contact, preferred leg kicks were characterised by greater kick leg foot velocities, greater pelvis linear velocities, greater knee angular velocities, and smaller hip angular velocities. However, they were lower than what has been recorded for senior elite men (Ball, 2008; 2011) and junior elite men AF athletes. Foot velocities for females were found to be $18.9 \text{ m/s} \pm 1.2$, and ball velocity of $24.7 \text{ m/s} \pm 1.4$ for preferred leg kicking, compared to $26.5 \pm 2.5 \text{ m/s}$ and ball velocities of $32.6 \pm 4.4 \text{ m/s}$ in elite senior men (Cust et al., 2019). This is possible for the differences in distance kicking as there has been found to be a strong correlation between foot speed and kicking distance (Ball,

2008). Having a more extended support leg will allow for a larger foot velocity and then ball velocity, due to the larger lever length available. However, this is unknown as there has been no research completed looking at support leg mechanics for females. In comparison to senior AF male athletes, greater knee angular velocities, and greater mean knee and hip angles, and lower hip angular velocities, were achieved by elite female AF athletes .

3.2 Support Leg in AF:

The support leg has been found to be important when kicking for distance. The support leg knee angle, and time on the ground were associated with foot speed (Ball, 2013). Seven elite AFL players kicked Sherrin footballs maximally from a 4-6 step run-up. An Optotrak system (London, UK) sampling at 200 Hz collected 3D kinematic data of the kick and support leg whilst an AMTI force plate (1200mm x 60mm, Watertown, Massachusetts, USA) measured GRF under the support leg (1000 Hz). Kinematic measures showed a more extended support leg knee at foot strike ($r = -0.73$, $P = 0.004$), a lower maximum knee flexion ($r = -0.71$, $P = 0.006$) and a shorter stance time ($r = -0.71$, $P = 0.006$) were significantly associated with kick leg foot speed at ball contact. Maintaining a more extended knee may be related to maintaining a higher kick leg hip, which would allow for a more extended leg during the swing phase near ball contact leading to a longer lever length (Ball, 2013). While all results indicated a large effect existed when kicking for distance, more work with a larger sample size is warranted for further validation.

When examining the GRF of the support leg when kicking for distance, peak vertical and posterior (braking) forces were associated with foot speed (Ball, 2013). The vertical forces had an initial peak at support leg landing, followed by a second during mid-stance, whilst anterior-posterior forces were directed solely posteriorly for the entire stance phase, and medio-lateral force patterns varied (Ball, 2013). The max vertical force was 2416 N (3.0 BW) for the preferred leg kick, which were larger than comparative soccer research (Kellis et al., 2004), and the anterior-posterior forces of 1.0 BW (775 N) were also higher than those of the soccer study. Due to the straighter approach angle when kicking in AF, the anterior-posterior forces are more likely to be greater than the medio-lateral forces which was evident during this study (775 N vs 262 N). The medio-lateral load differed for different players with some having largely lateral GRF, some medial GRF and both within the stance phase, which may indicate different approach angles taken by the players, different kicking techniques, different abilities to balance on the support leg, however, it always remained lower than the vertical forces. When examining the kinematics, Ball (2013) found that there was a pattern similar to what has been recorded in soccer where the support-leg knee extends

before ball contacts, stabilizing the movement. Helping to maintain a high kick leg hip, which would allow for a more extended leg during the swing phase near ball contact creating a longer lever is beneficial for distance kicking. This literature provides a platform to build off of with different approach speeds being added and allows for comparisons to see how different approach speed may affect the support leg when compared to a standard movement speed.

The support leg has also been found to be linked to kick accuracy, but findings have been conflicting. Eighteen elite to sub-elite AF players performed 15 x 30 m goal-kicks with three-dimensional kinematics collected using Xsens inertial measurement system (Xsens Technologies B.V., Enschede, the Netherlands) (Blair et al., 2020). The study examined kinematic differences between accurate and inaccurate goal-kicks and determined relationships between technical factors and accuracy (Blair et al., 2020). More accurate kickers were found to exhibit a more extended support leg during the kick compared to less accurate kickers. Blair et al. (2020) suggested a stronger and more stable stance leg during the kicking motion might enable better control and regulation of the kick-leg movement. Notably, Blair et al. (2020) found that players tended to exhibit less support leg knee flexion when missing to the left and more knee flexion when missing to the right, among right-foot dominant players. A greater knee flexion would allow for less trunk rotation to take place, due to the inability to rotate fully through the kicking action to get the ball straight (Blair et al., 2020). Conversely with less knee flexion, this may lead to over rotation leading to kicks missing to the left. Support-leg knee flexion had a large magnitude of effect when comparing accurate kicks ($38^{\circ} \pm 5$) to inaccurate ($48^{\circ} \pm 7$) during the kicking phase at ball contact. However, at support heel strike there was only a small effect (accurate = $23^{\circ} \pm 6$, inaccurate = $25^{\circ} \pm 4$) and ankle dorsiflexion and hip flexion did not differ between accurate and inaccurate kicks. Previous Dicheria et al. (2006) findings were also reflective of what Blair (2020) found, where Dicheria et al. (2006) found no significant difference in ankle kinematics between accurate and inaccurate kicks at either heel contact or ball contact. However, in contrast to the findings in Blair et al (2020), Dichiera et al (2006) found that more accurate kickers exhibited a greater knee flexion for 15m kicks compared to less accurate kickers. The support leg knee angle was very similar to Blair et al., (2020) at $22^{\circ} \pm 3$ and knee flexion at ball contact was $43^{\circ} \pm 6$. In the Dicheria et al. (2006) study, 10 professional AFL players performed 20 drop punt kicks towards a target at 15 m. A three-dimensional motion analysis system (Vicon, Oxford Metrics Ltd., UK) was used to record the kicking motion from heel contact of the support limb through to ball contact. Participants were then split into two groups of accurate and inaccurate kickers, where the kinematic profiles of both kicking and support limbs were compared between the groups (Dichiera et al., 2006).

This conflict in the literature needs more research to better define the importance of the support leg in kicking, with approach speed a potential factor for the differences, Blair et al (2020) reported a maximum speed run-up speed of 4.1 m/s, although it wasn't defined where in the run-up this maximum occurred. Dichiera et al., (2006) did not report approach speed and only a few steps were possible due to the lab environment. The approach speed was therefore likely slower than the 10-20m run-up performed in the Blair et al., (2020) study. A similar approach (3-4 steps) was performed in maximal kicking in male AFL players (Ball, 2013) with an average of 3.38 m/s reported which might support that of the Dichiera et al., study. This led to the conclusion that approach speed might have been a factor in the different findings of support leg function between the two studies.

The other factor that might be relevant to the contrasting findings is the different kick distances. A more extended support leg has been found to be associated with greater foot speed (Ball, 2013). A more extended kick leg was found to be associated with greater kick leg foot speed (which is strongly related to kick distance) (Ball, 2008). Ball (2013) indicated that this more extended support leg knee might be due to players attaining a higher kick leg hip position which in turn allows for a longer lever with a more extended kick leg.

3.3 Support Leg in other kicking sports:

The support leg has been found to be beneficial in other kicking sports for both accuracy and distance. When examining the support foot touchdown in soccer instep kicking, Inoue et al. (2014) found that there was sudden plantarflexion of the ankle joint from the instant of touch-down, which contrasted with previous studies. There was rapid ankle inversion/eversion and hip external rotation motions appeared instantaneously after touch-down. Kellis et al. (2004) found that all kicks demonstrated similar knee extension-flexion and abduction-adduction motion. Kellis et al. (2004) examined support leg of soccer place kicks when the player has three different approaches at, 90°, 45° and 0° to understand how the support leg can adapt and allow the player to perform when the conditions are different. During the 0° approach kick, the tibia externally rotated relative to the femur, which serves to accommodate and enhance the swinging movement of the kicking leg towards the ball. During the support phase, no key differences were found in either the support or swinging leg displacements in each of the three approaches.

Previous studies had found that the support leg produced large ground reaction forces in excess of two times body weight (Kellis et al., 2004), and a similar result was found by Inoue et al.

(2014). Inoue et al. (2014) speculated that the support leg has two major roles; 1) to resist the large external force to stabilise the body and/or 2) to transfer the mechanical energy to the proximal segment, leading to a proximal-distal sequential motion of the swing leg. The ankle joint was found to never exhibit power through the support phase, as it works exclusively for absorbing the large external force from the ground, which is reasonable as it is the most distal joint and receives the GRF first. Immediately before the ball impact the knee extension motions came to be associated with the knee extension joint moments. The positive power from this was in the support leg just before the ball impact, where the knee extensors of the support leg were exhibiting concentric contraction during this phase (Inoue et al., 2014).

When examining the GRF from three different approach angles, Kellis et al. (2004) found that there was no significance difference in vertical GRF, however, the kick from 90° and 45° had significantly higher mediolateral and posterior GRF than the 0° kick. Anterior GRF were lower in the 90° compared to the 0° and 45°. Kellis et al. (2004) reported that the soccer kick induces vertical GRF similar to running at 3.8 m.s⁻¹, including starting and stopping, and cutting. Posterior GRF are higher compared with running, and approximately 40% lower compared to landing, stopping, and cutting. The study indicated that the 90° kick approach had a longer braking phase which results in higher posterior GRF compared to other kicks. The medial GRF increased with increasing approach angle reaching maximum values immediately after ground contact, which agrees with previous studies that as approach angle increases there is a lateral body inclination leading to increased medial GRF.

When examining the dynamic interaction between the support leg and pelvis, Inoue et al (2014), found that the angular velocity of the pelvis did not exhibit a marked change before the touch-down. However, a sudden transition of the pelvis angular velocity was observed from the instant of touch-down of the support leg after which angular velocity continued to increase until the middle of the support leg (Inoue et al., 2014). The touch-down of the support leg seemed to trigger the rapid pelvis rotation, the joint reaction force of the support leg side attributing to the ground reaction force was the most dominant factor to induce this counter-clockwise pelvis rotation (Inoue et al., 2014).

In soccer kicking, the support leg has been linked to enhanced ball velocities. Zhang et al., (2025), found that ball velocity increased with greater peak extension angular velocity of the support leg hip. After support foot touch down, the hip continued to extend, reaching peak

angular velocity prior to ball contact, allowing for a prolonged acceleration pathway for the kick leg (Zhang et al., 2025). This aligns with Augustus et al., (2017), where they found having increased knee and hip extension in the support leg enhanced vertical displacement, elevating the pelvic position, allowing for the kick leg to initiate its downswing from a higher point. Zhang et al., (2025), continued by stating that a higher peak extension angular velocity of the support leg knee also increased ball velocity, while excessive hip external rotation angular velocity had a negative effect.

3.4 Approach speed in kicking:

Kicking sports often have changes of speed between fast and slow movements, requiring athletes to perform kicks effectively when running fast or slow (Bradley et al., 2009). Kicking at different approach speeds has not been examined in AF but a number of papers exist in soccer. Augustus et al. (2021) examined the effect of approach speed on pelvis and kick leg angular velocity and found that the support leg was used to regulate whole-body deceleration and create ideal conditions for co-ordinated pelvic and kick leg momentums during the downswing. The pelvis was also key for creating transverse momentum for the kick leg. Augustus et al. (2021) found that the ball velocities from slow approaches were not different to standard speed (24.4 ± 1.1 m/s vs 25.7 ± 2.0 m/s), but fast approaches induced faster ball speeds (26.9 ± 1.6 m/s). Further, kick leg foot speeds were slower in the slow (17.2 ± 0.9 m/s) and faster in the fast speed (19.2 ± 1.0 m/s) compared to the standard speed (18.1 ± 1.1 m/s). Slower approaches negatively affected both peak foot and ball velocities ($\sim 83\%$ of standard speed), whilst smaller increases of approach speed ($\sim 110\%$ of standard speed) were beneficial for generating faster foot and ball velocities, therefore adapting to a faster speed may be more beneficial if players are looking to perform faster kicks. When Anderson and Dörge (2011) examined the influence of approach speed in soccer, they added the constraint of accuracy, which found the speed of the ball to decline to 85% of maximal speed to make sure accuracy was achieved. The decrease in the maximal speed of the ball observed when hitting for accuracy could be related to the control and regulation of the intersegmental movement of the lower extremity to ensure the control of the path of the ball (Andersen & Dörge, 2011).

Specific to the support leg mechanics at different approach speeds, Augustus et al (2021) reported that while they expected that players would exhibit greater centre of mass deceleration at faster approaches this did not occur. Centre of mass deceleration impulses did not change under varying approaches and remained between 90 and 145 kg.m/s for speeds ranging between 2.77 m/s and

3.71 m/s. Typically large braking forces have been shown to slow the forward motion of the body, and it has been suggested that this action facilitates energy transfer. However, Augustus et al (2021) found that CoM deceleration and braking GRF similar under varying approach velocities, instead, players used the support leg to regulate absorption of GRFs and ensure optimal CoM deceleration for a given kick. Knee flexion velocities were slower in the slow compared to standard speed and fast approaches between support foot touchdown and ball contact start. The slow approaches were thus performed with a more extended support leg to compensate for the lack of forward velocity and ensure the CoM deceleration was similar to the standard speed and the fast approach kicks. Support foot touchdown was found to induce considerable pelvic backwards tilt and transverse rotation of the kicking hip towards the ball, and momentum is proposed to be transferred from the torso to the kicking leg throughout the kicking phase. As approach speed in kicking has little research, this research will allow help guide knowledge in AF and determine if there are any differences between soccer and AF.

3.5 Male vs Female mechanics:

Biomechanical differences are evident between male and female kickers in kicking based sports (Boyne et al. 2024, Cust, 2019). This hasn't been studied in AF, but as the athletes will be moving at different speeds, running mechanics may provide detail differences that may occur. Ferber et al., (2003), made comparisons of hip and knee joint angles during the stance phase of running between male and female participants. There were no differences in the sagittal plane hip and knee kinematics or kinetics. However, in the frontal plane, females exhibited significantly greater peak hip adduction angle ($p= 0.05$) and hip frontal plane negative work ($p= 0.01$) whilst running (Ferber et al., 2003). Females also demonstrated a greater peak hip adduction velocity (107.11 °/s female to 70.00 °/s male). Females also demonstrated a significantly greater peak knee abduction angle and were in a more abducted knee position throughout the stance phase. In the transverse plane, peak hip internal rotation occurred at heel strike followed by external rotation. The increased hip internal rotation angle likely led to the reduced peak external knee rotation compared to men. The increased hip internal rotation and greater knee abduction may result in a greater dynamic Q-angle (Ferber et al., 2003).

Within kicking, research has been completed in soccer, looking at sex differences in support leg dynamics (Iitake & Iwasaki, 2024). Twenty male and 20 female soccer players performed maximal instep kicks, where female players had significantly lower knee joint torque (58~100%) and knee joint power (82~100%). It was found that females were unable to lift their whole-body

using knee extension joint torque in the support leg as effectively as the male players were able to. Without being able to perform whole-body lift this will impact ability to kick for distance as found by Ball (2008) as it allows for a longer kick leg lever length but also, for potential of greater kick foot speed development. Female athletes generated a comparable level of external torque compared to male athletes due to the GRFs, however female athletes exhibited significantly smaller knee extension joint torque in the latter stages of the instep kick. This resulted in female athletes being unable to exert enough knee extension joint torque to counteract the external torque. In rugby place kicking, female kickers presented a significantly smaller support leg knee extensor moment following support foot contact and significantly slower support leg hip extension velocities (Atack & Bezodis, 2023). This indicates that females were less effective in transferring momentum from the approach to their kick leg. Therefore, leading to females relying on generating velocity through forceful contraction of their kicking leg hip flexors and knee extensors (Atack & Bezodis, 2023). Generating velocity through hip flexor dominance has previously been associated with less accurate kicking (Atack et al., 2019).

When examining kick-leg mechanics, research has been done in rugby place kicking and soccer, both have indicated significant differences between genders. Atack & Bezodis (2023) reported that females achieved significantly shorter predicted maximum distances and slower ball and kicking foot velocities compared to males. This has been found in soccer by Katis et al., (2015) and Boyne et al., (2024), where males reported significantly greater ball velocities. Boyne et al., (2024) reported that males were more efficient in proximal-to-distal sequencing during kicks, due to having significantly greater distal lower limb joint angular velocities. The potential and kinetic energies of the thigh and shank were higher in male athletes than females, leading to greater energy transfer values (Boyne et al., 2024). Males were able to produce greater foot velocities, in combination with the optimal sequencing and energy transfer pattern in males may be contributing factors to their greater ball velocities (Boyne et al., 2024).

The literature highlights that kicking for accuracy and distance in AF is strongly influenced by support-leg mechanics. Greater kicking distance is associated with higher foot speeds, and a more extended support leg during stance, which assists in maintaining pelvic height and creating a longer kicking-leg lever (Ball 2008; Ball, 2013). Research examining fast vs slow approaches suggests that faster run-ups produce greater foot and ball velocities, while slow approach speed kicks resulted in reduced foot and ball velocities and greater reliance on a more extended support leg to compensate for reduced momentum (Augustus et al., 2021). Soccer literature indicates that

the support leg plays a key role in regulating ground reaction forces, pelvic rotation, and energy transfer during varying approach conditions (Kellis et al., 2004; Inoue et al., 2014). When comparing male and female athletes, females demonstrated lower foot and ball velocities, reduced knee extension torque and power, and less effective momentum transfer through the support leg than males (Cust et al., 2019; Iitake & Iwasaki, 2024; Attack & Bezodis, 2023). Females therefore appear to rely more heavily on hip flexor driven kicking actions, whereas males demonstrate more efficient proximal to distal sequencing and greater energy transfer through the kicking motion (Boyne et al., 2024). These findings suggest that support-leg function is fundamental for both kicking distance and accuracy, while differences in approach speed and gender likely alter the strategies used to generate and transfer momentum during the kick.

4.0 Methods

4.1 Participants:

Nineteen male and 17 female AF athletes volunteered to participate in this study, providing written consent. All participants were current AF players. Of the 19 males (24.28 ± 4.65 , 187 ± 7.88 cm, 85.09 ± 8.26 kg), 5 were elite level, 2 sub elite, and 12 high level amateurs. Among the female athletes (23.41 ± 4.05 , 171.06 ± 8.45 cm, 68.53 ± 10.42 kg), 16 competed at an elite level with 1 sub-elite at the time of the study. The study was approved by Victoria University's Human Research Ethics Committee - HRE24-093.

4.2 Research Procedures:

4.2.1 Lab Set-up:

All kinematic and kinetic data was recorded at Victoria University within its biomechanics lab. A synthetic turf strip of 20m was unrolled within the lab space to allow participants to wear their boots to allow the testing to be as realistic as possible to normal kicking conditions within AF (Figure 2). To ensure the force plates were independent of the surrounds, a section that covered four force plates was cut from the main roll and positioned on the force plates while not touching the main turf section (Figure 3). As GRF data was aggregated across all four force plates, no separation between each force plate was required. The use of four force plates allowed for a large test area for participants to kick from, ensuring the run up was not compromised by having to land on a single force plate. Surrounding this kicking zone were 14 Vicon cameras (10x T40 and 4x Vantage 6 cameras) to capture the area over the force plates where players would make impact with the ball during the kick. The majority of participants kicked towards a target placed 35 m away (Figure 4). Restrictions existed for some participants whereby they were required to kick into a net and for this condition, tape was placed on the net indicating a straight kick in line with the middle of the force plates (Figure 5). Data were compared between the two conditions before proceeding with the inclusion of both test set ups in the full analysis (Appendix A).



Figure 2: Turf set-up

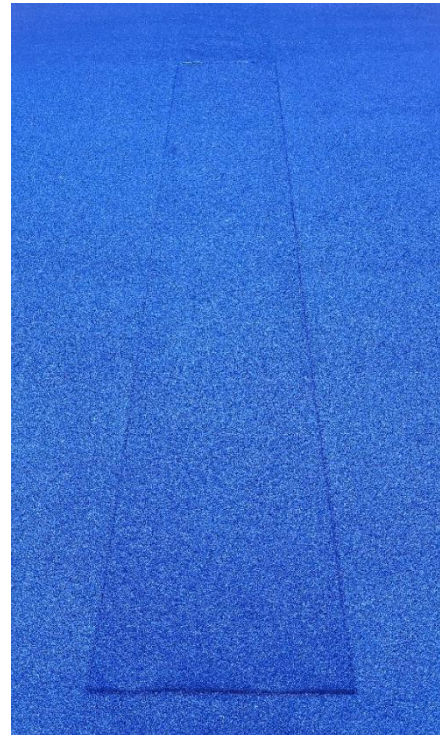


Figure 3: Force plate turf cut-out

During each kick, 3D coordinate data were recorded via the Vicon Nexus (2.15) motion capturing system (Vicon Motion Systems, Oxford, UK), sampling at 200 Hz, using the passive reflective markers located on the athlete (figure 6) and ball (figure 7). All kicks were performed on AMTI force plates (Advanced Mechanical Technologies Inc., Massachusetts), 1000 Hz, to collect kinetic values (i.e. peak vertical and anterior-posterior forces). The use of four force plates removed player positioning restrictions when kicking (4 plates 90x60 cm).



Figure 4: Target when kicking outdoors

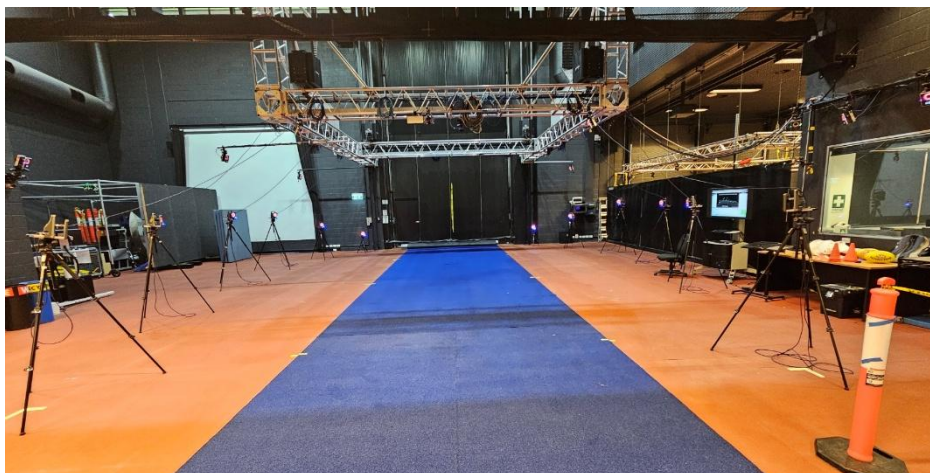


Figure 5: Set-up with drop net

4.2.2 Marker Set-up:

To gain three-dimensional positional data of the participant, a whole-body marker set comprising of 50 passive reflective markers placed was used. Clusters were placed on the thigh, shank, upper and lower arm of the participants. Individual markers were placed on the anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), lateral and medial aspect of the knee, ankle, elbow, and wrist, mid-hand, finger, heel, lateral calcaneus, head of the 5th and 1st metatarsal, top of the shoulders, sternum, T10, C7, mid of clavicles (sternoclavicular joint), and posterior and



Figure 6: Anterior and Posterior markers used during testing

anterior of the head (via headband), on both sides of the body (Figure 6) (Ball, 2013; Blair et al., 2020). All markers were placed with the participant wearing a Velcro motion capture suit. All medial markers, except for the medial wrist marker, head of the 1st metatarsal and finger markers were removed once the static capture file had been recorded.

To track the ball, four markers were placed on the ball (Figure 7). The markers were glued onto 3 sides of the ball, with 2 on one side next to the laces of the ball, and with a marker on each side of the underside of the ball. One of the quarters next to the laces was kept clear of markers to avoid any issues for the participants holding the ball allowing it to be as close to game like scenario as possible. A marker was placed at each end of the ball (Figure 7) during the static capture only. A similar marker setup has been used in previous kicking research (Blair et al., 2020). Balls were placed on cones for the static captures so that all 4 active markers during testing could be recorded along with the two static only markers located at the points of the ball to create a ball model.



Figure 7: Marker locations on ball

4.2.3 Task:

Players completed a warm-up, comprised of going through necessary stretches, and progressively building up kicking distance to the required 35m (10-15 kicks), prior to getting changed into the motion capture suits. Once the participant was changed and the markers were placed on them, they were instructed to complete further warm-up kicks and familiarisation kicks within the

testing space. All participants reported feeling comfortable and could complete the required kicks as they would during games. A static capture of each player was taken, prior to any testing. The player then performed five kicks using a slow approach speed and five using a fast approach speed. The order of kicks was randomised with the order consistently changing between fast and slow approach kicks. For the slow approach kicks, players were instructed to limit their approach to 2-3 m before the kick just like in a match scenario, where footballers are kicking the ball at the slowest approach speed, commonly where they take a mark and take a couple of steps before performing the kick in a slow passage of play. For the fast approach speed kicks, players were instructed to have a run-up of 10-15m, or however long they felt comfortable to get to 80% max speed, approach length and told, 'imagine you are running down the wing on a fast break'.

Speeds after the first slow and fast approach kicks were identified by looking at the support leg ASIS, and feedback was reported back to the athlete. The target speed for the slow approach kicks was <3.5 m/s, and >4.5 m/s for fast approach kicks. If approach speed was considered to be too fast or slow, if the player reported feeling a miskick or if the player didn't land fully on the force plates, an extra kick at the select speed was taken at the end of the original testing order. The players performed a typical drop-punt, the most common type of kick in AF (Ball, 2008). When kicking outdoors, a target was set-up 35m away from the centre of the force plates, with participants instructed to hit the target. If any of the kicks were deemed to have fallen too short of the target distance or travelled too far, the kick was retaken at the end. When kicking into the net, players were told to imagine the kick was travelling approximately 35m same distance for the fast and slow approach kicks. Kick foot 5th metatarsal marker velocity was looked at to see if the same kick distance was being completed, as foot speed is a key factor in kicking distance (Ball, 2011). Players used the ball size they use in competition (male players size 5, female players size 4).

4.3 Analysis:

4.3.1 Data Processing:

All trials were labelled in Vicon Nexus 2.15.0, where all trials that were considered acceptable from the criteria mentioned above, were labelled from prior to contact with any force plates through to end of follow through (Figure 8). All trials were gap filled when needed using pattern fill or rigid body fill. Trials were then transferred to Visual 3D (C-Motion Inc., Germantown, MD, USA), where the labelled data was combined with a 3D model of each player built from their static trials (Figure 9). Data was then smoothed using a low pass Butterworth digital filter at 9.5

Hz for kinematic data, and 25 Hz for kinetic data, similar to previous AF kicking research (Ball, 2013). The smoothing cut-off was determined using a combination of wavelet analysis, residual analysis, and visual inspection of raw and smoothed curves. As there is impact occurring during the movement, the foot and ball data were not smoothed through contact, to avoid any errors in position and velocity data before impact (Knudson & Bahamonde, 2001).

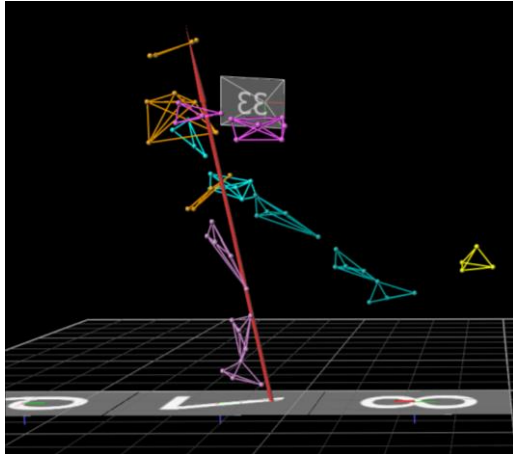


Figure 8: Labelled data in Vicon



Figure 9: Skeleton model in Visual 3D

4.3.2 Data analysis:

Each trial went through event labelling which was completed in Visual 3D. The key moments were: support foot touchdown (first impact with the ground as defined by force plate), ball contact (the frame immediately before the ball came into contact with the foot), and maximal and minimal values. Visual inspection of the foot (5th metatarsal) and ball velocities were visually inspected to ensure these moments were correctly identified, where the peak foot velocity in the Y axis indicated the instant before ball contact (Cust et al., 2019; Ball, 2013; Ball, 2008). Joint angles/angular velocities were calculated between support foot landing and ball contact (Table 1). For continuous data, all data was normalised from support foot landing (0%) until ball contact (100%) to allow for continuous data comparisons (Table 1). GRFs were quantified for peak forces in the vertical and anterior-posterior directions, as well as at ball contact (Ball, 2013). GRFs were normalised to body weight, to remove the individual influence of mass from each participant. Athlete approach speed was calculated for each kick, which was determined by examining their maximal centre of mass velocity right before support foot touchdown.

If the maximum and minimum parameters occurred at support foot touchdown or ball contact, the maximum and minimum parameters were removed from the analysis. This occurred with the

following parameters; knee angle max and knee angle support foot touchdown, hip angle max and hip angle at ball contact, hip angle minimum, and hip angle at support foot touch down.

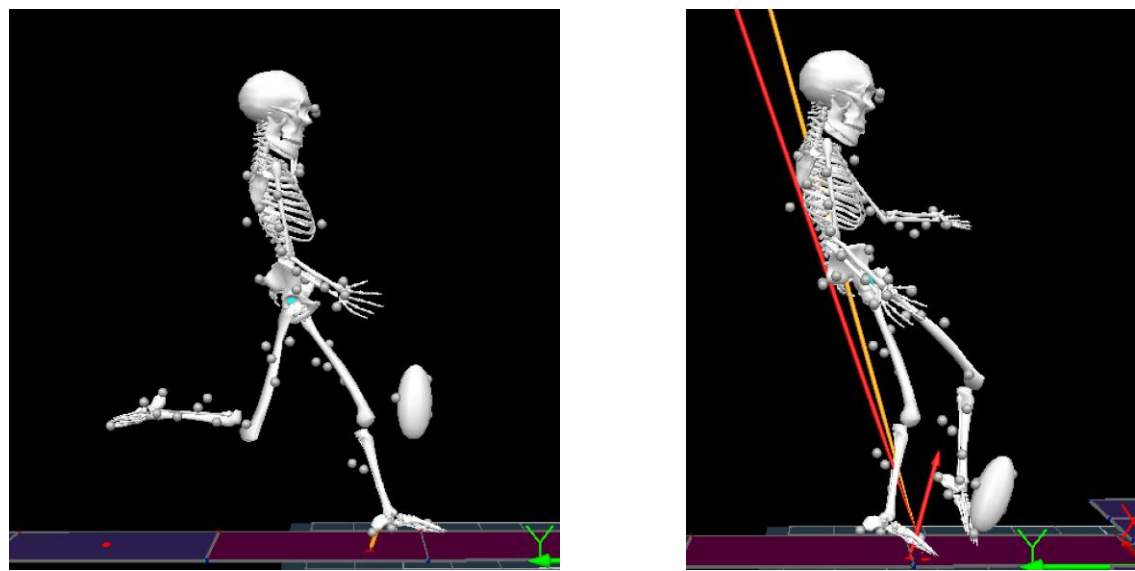


Figure 10: Support Foot Touchdown (0%) to Ball Contact (100%)

Table 1: Support Leg Parameters

Parameter	Rationale	Time of measurement
Knee angle	Support leg knee angle is important for distance (Ball, 2013) and accuracy (Blair et al, 2020; Dicheria et al, 2006)	Support leg landing Ball Contact Max and/or Min Continuous measurement
Knee angular velocity	Has not been studied in AF. Has been found to be important in soccer (Inoue et al, 2014)	
Hip angle	Has been associated with more accurate kicking (Blair et al, 2020)	
Hip angular velocity	Was an indicator of performance when kicking under fatigue (Coventry et al., 2015)	
GRF	GRF related to kicking performance (Ball, 2013)	

4.3.3 Trial Selection:

Of the 5 kicks that were taken at each approach speed, only 3 were used for analysis. Trials that were used for analysis were determined by each trial's foot and ball speed. This was done to determine that each kick that was being analysed were kicking a similar distance which can be determined by examining foot and ball speeds. When kicking onto the oval, observation to gauge the correct distance was achieved, and then foot and ball speeds were examined. The 3 fast and 3 slow approach speed trials which had the most similar foot and ball speeds were selected to undergo further analysis and be included in future comparisons.

4.3.4 Statistical analysis:

To analyse the technical parameters in Table 1, mixed-design ANOVAs were used to investigate the main effects of gender (male and female) and speed (fast and slow), as well as their interaction for each parameter. If no significant gender*speed interactions were observed, main effects of gender and speed were analysed. Sphericity was tested using Mauchly's test of Sphericity for all data, to indicate that the variance of differences between all pairs of repeated measures are equal. ANOVA effect sizes were reported using partial eta squared (η^2_p) and interpreted according to Cohen (1988; Small = >0.01 , medium = >0.06 , large = >0.14). Pairwise comparisons were conducted for any significant interactions or with main effects, with an alpha value of 0.05. If no interaction or main effects were observed, there was no further analysis of the data. Effect sizes for pairwise comparisons were reported using Cohen's d (small = <0.5 , medium = <0.8 , large = >0.8). All discrete data was analysed in SPSS (version 29; IBM Corp., Armonk, NY, USA).

To compare time series data, statistical parametric mapping (SPM) mixed design ANOVA was conducted in MATLAB (MathWorks Inc., Natick, MA, USA) using SPM1D (Pataky, 2012). All parameters were normalised to 101 points to represent the phase of support foot touchdown through to ball contact. All parameters were tested initially for an interaction or if main effects were observed. An alpha value of 0.05 was used for interactions and main effects to determine if *post-hoc* independent or paired-sample t tests were needed to be performed. Random field theory was used to adjust the statistical significant levels to control for Type 1 and Type 2 errors, as well as reducing bias that could arise from multiple separate tests.

All data was presented as mean $\pm$ standard deviation ($M \pm SD$).

5.0 Results

5.1 Velocity Parameters:

Table 2 reports approach speed as well as foot speed, ball speed, and ball flight trajectory. Approach speed was significantly greater ($p < 0.001$) for fast approach ($5.0 \text{ m/s} \pm 0.6$) compared to slow approach kicks ($2.9 \text{ m/s} \pm 0.38$). Foot speeds were significantly different ($p < 0.001$) with fast approach kicks having greater foot speed velocity ($21.8 \text{ m/s} \pm 1.55$), compared to slow approach kicks ($19.2 \text{ m/s} \pm 1.51$). Slow approach kicks exhibited greater trajectory angle ($27.7^\circ \pm 4.36$) compared to fast approach kicks ($24.5^\circ \pm 4.15$). Males showed significantly higher approach speeds, foot and balls speed and lower trajectory angles compared to females. Ball speeds were found to have a significant interaction between gender and speed ($p = 0.026$) (Table 3).

Table 2: Velocity Parameters

Parameter	Female		Male		Gender*Speed	Speed	Gender
	Fast M (SD)	Slow M (SD)	Fast M (SD)	Slow M (SD)	p (η^2_p)	p (η^2_p)	p (η^2_p)
Approach Speed (m/s)	4.7 (± 0.5)	2.7 (± 0.4)	5.3 (± 0.6)	3.0 (± 0.3)	0.052 (0.106)	<0.001 (0.942)	0.004 (0.223)
Foot Speed (m/s)	20.7 (± 1.0)	18.3 (± 1.0)	22.9 (± 1.2)	20.0 (± 1.5)	0.109 (0.074)	<0.001 (0.888)	<0.001 (0.448)
Ball Speed (m/s)	21.4 (± 1.2)	20.6 (± 1.2)	24.8 (± 1.3)	23.3 (± 1.4)	0.026 (0.138)	<0.001 (0.608)	<0.001 (0.619)
Trajectory Angle ($^\circ$)	26.6 (± 3.2)	30.3 (± 3.2)	22.5 (± 4.0)	25.3 (± 4.0)	0.388 (0.022)	<0.001 (0.520)	<0.001 (0.342)

M: Mean, SD: Standard Deviation, p : Significant Difference, η^2_p : Partial Eta Squared

Table 3: Ball Speed Gender*Speed Interaction

Gender*Speed	Fast	Slow	Mean difference	Sig
Males	24.778	21.388	1.49	<0.001*
Females	23.289	20.624	0.77	0.002*
Mean Difference	3.389	2.665		
Sig	<0.001*	<0.001*		

5.2 Discrete Values:

Table 4 reports all the discrete values interactions and main effects for all comparisons. These findings are repeated (significant results only) in tables 4-5 with greater detail under the headings fast and slow approach, and male compared to female to assist in communicating the results more clearly. If there was no interaction (Gender*Speed) or main effect of speed (<0.05), the parameter was not further examined and so is not reported in Tables 5 or 6. There were no interactions present within this parameter set, however, there were significant differences when looking at main effect of speed. Repeating from methods for clarity, if the maximum and minimum occurred at support foot touchdown or ball contact, the maximum and minimum were removed from the analysis

Table 4: Discrete Values

Parameter	Female		Male		Gender*Speed	Speed
	Fast M (SD)	Slow M (SD)	Fast M (SD)	Slow M (SD)	p (η^2_p)	p (η^2_p)
KAngSFTD (°)	169.7 (± 5.2)	169.5 (± 5.4)	168.1 (± 5.5)	168.8 (± 3.5)	0.406 (0.020)	0.764 (0.003)
KAngBC (°)	151.0 (±7.7)	156.7 (±8.1)	144.1 (±10.4)	149.2 (±7.2)	0.795 (0.002)	<0.001* (0.417)
KAngMin (°)	144.8 (±6.6)	148.6 (±5.8)	140.7 (±7.5)	146.3 (±5.3)	0.272 (0.035)	<0.001* (0.526)
KAngVelSFTD (°/s)	-155.9 (±61.7)	-82.4 (±69.7)	-188.5 (±93.3)	-127.6 (±55.9)	0.634 (0.007)	<0.001* (0.435)
KAngVelBC (°/s)	87.5 (±124.0)	107.2 (±90.9)	75.1 (±117.2)	95.2 (±82.2)	0.992 (0.000)	0.196 (0.049)
KAngVelMin (°/s)	-580.3 (±80.2)	-464.3 (±77.0)	-574.7 (±98.6)	-416.6 (±68.8)	0.090 (0.082)	<0.001* (0.791)
KAngVelMax (°/s)	181.8 (±89.9)	178.8 (±77.6)	102.8 (±122.1)	101.7 (±82.9)	0.951 (0.000)	0.891 (0.001)
HAngSFTD (°)	142.2 (±6.2)	139.8 (±7.6)	146.7 (±4.2)	145.6 (±4.3)	0.141 (0.063)	<0.001* (0.319)
HAngBC (°)	191.3 (±5.1)	188.4 (±5.9)	192.5 (±6.5)	188.1 (±5.4)	0.202 (0.047)	<0.001* (0.545)
HAngVelSFTD (°/s)	-231.5 (±66.9)	-211.1 (±68.5)	-231.9 (±87.5)	192.5 (±56.7)	0.500 (0.0.14)	0.039* (0.12)

HAngVelBc (°/s)	-176.8 (±155.9)	-244.4 (±139.9)	-268.5 (±89.8)	-313.8 (±60.0)	0.394 (0.021)	<0.001* (0.363)
HAngVelMax (°/s)	-81.6 (±97.7)	-87.2 (±92.5)	-149.8 (±61.1)	-135.1 (±58.0)	0.323 (0.029)	0.654 (0.006)
KAngVelMin (°/s)	-661.8 (±115.6)	-548.1 (±116.0)	-619.5 (±105.0)	-488.8 (±87.3)	0.357 (0.025)	<0.001* (0.855)
AP GRF BC (BW)	0.09 (±0.17)	0.44 (±0.15)	0.09 (±0.18)	0.37 (±0.14)	0.299 (0.032)	<0.001* (0.717)
AP GRF Max (BW)	0.77 (±0.21)	0.79 (±0.27)	0.59 (±0.19)	0.49 (±0.15)	0.102 (0.077)	0.307 (0.031)
Vertical GRF BC (BW)	1.99 (±0.33)	1.92 (±0.34)	1.98 (±0.33)	2.07 (±0.20)	0.083 (0.086)	0.912 (0.000)
Vertical GRF Max (BW)	3.54 (±0.47)	2.74 (±0.32)	3.41 (±0.53)	2.62 (±0.38)	0.983 (0.000)	<0.001* (0.825)

M: Mean, SD: Standard Deviation, *p*: Significant Difference, η^2p : Partial Eta Squared, *: significant difference (<0.05)

5.2.1 Fast vs Slow:

There were significant differences present within slow vs fast approach kick kinematics, however there were no significant interactions present (Table 5).

Table 5: Fast vs Slow Results

Parameter	Fast	Slow	Mean Difference	F	Sig	Cohen's <i>d</i>
KAngBc (°)	147.4 (±9.3)	152.7 (±7.7)	-5.34	24.297	<0.001*	0.63
KAngMin (°)	142.7 (±7.1)	147.4 (±5.6)	-4.71	37.740	<0.001*	0.74
KAngVelSFTD (°/s)	-172.2 (±80.1)	-150.0 (±62.9)	-67.19	26.211	<0.001*	0.93
KAngVelMin (°/s)	-577.5 (±90.5)	-440.5 (±72.9)	-137.02	129.022	<0.001*	1.67
HAngSFTD (°)	144.5 (±5.3)	142.7 (±6.1)	1.76	15.961	<0.001*	0.31
HAngBC (°)	191.9 (±5.9)	188.3 (±5.7)	3.63	40.682	<0.001*	0.63
HAngVelSFTD (°/s)	-231.7 (±78.6)	-201.8 (±62.6)	-29.87	4.642	0.039*	0.42
HAngVelBc (°/s)	-222.6 (±125.5)	-279.1 (±105.6)	56.46	19.354	<0.001*	0.49
HAngVelMin (°/s)	-640.1 (±110.3)	-518.4 (±101.9)	-121.72	200.960	<0.001*	1.15
AP GRF BC (BW)	0.09 (±0.17)	0.41 (±0.15)	-.314	86.302	<0.001*	1.93
Vertical GRF Max (BW)	3.48 (±0.50)	2.68 (±0.36)	0.795	160.269	<0.001*	1.82

Sig: Significance <0.05 *, Effect size: *d*, small = 0.2, medium = 0.5, large = 0.8

Knee angular velocity + = extension, - = flexion, Hip Angular Velocity - = extension, + = flexion

5.2.1.1 Knee:

A significant main effect of approach speed was observed for all knee kinematic variables, with slower approaches producing more extended knee angles at ball contact and at minimum knee angle, while faster approaches resulted in greater knee flexion velocities at support foot touchdown and at peak flexion (Table 5; all $p = < .001$). Specifically, knee angles were approximately 5° greater during slow compared with fast approaches, whereas knee flexion velocities were substantially higher during fast approaches.

5.2.1.2 Hip:

A significant main effect of approach speed was observed for all hip kinematic variables (Table 5). Fast approaches resulted in slightly more extended hip angles at support foot touchdown (1.76°) and at ball contact (3.63°) compared with slow approaches ($p = < .001$). Hip angular velocity differed across phases, with faster approaches producing greater hip extension velocity at support foot touchdown ($p = .039$) and at peak extension ($p = < .001$), while slow approaches produced greater hip extension velocity at ball contact ($p = < .001$).

5.2.1.3 GRF:

A significant main effect of approach speed was observed for anterior–posterior and vertical ground reaction forces (Table 5; both $p = < .001$). Slow approaches produced substantially greater posterior ground reaction forces at ball contact, whereas fast approaches resulted in higher maximal vertical ground reaction forces, with large effect sizes.

5.2.2 Male vs Female:

There were significant differences present within male vs female kinematics, however there were no significant interactions present (Table 6).

Table 6: Male vs Female Results

Parameter	Female	Male	Mean Difference	F	Sig	Cohen's <i>d</i>
KAngBc (°)	153.9 (±7.9)	146.6 (±7.4)	7.22	7.597	0.009*	0.95
KAngMin (°)	146.7 (±5.9)	143.5 (±5.6)	3.21	2.639	0.113	0.56
KAngVelSFTD (°/s)	-119.1 (±60.2)	-158.0 (±56.9)	38.88	3.741	0.61	0.66
KAngVelMin (°/s)	-522.3 (±73.7)	-495.7 (±69.7)	26.67	1.174	0.286	0.37
HAngSFTD (°)	141.0 (±5.5)	146.2 (±5.2)	5.14	7.721	0.009*	0.95
HAngBC (°)	189.9 (±5.5)	190.3 (±5.2)	0.412	0.50	0.824	0.08
HAngVelSFTD (°/s)	-221.3 (±57.5)	-212.2 (±54.4)	9.095	.224	0.639	0.16
HAngVelBc (°/s)	-210.6 (±109.3)	-291.2 (±103.4)	80.555	4.877	0.34	0.76
HAngVelMin (°/s)	-604.9 (±102.9)	-553.6 (±97.3)	51.294	2.229	.145	0.71
AP GRF BC (BW)	0.27 (±0.13)	0.23 (±0.12)	0.04	.917	.345	0.32
Vertical GRF Max (BW)	3.14 (±0.40)	3.02 (±0.38)	0.121	.849	.363	0.31

Sig: Significance <0.05 *, Effect size: *d*, small = 0.2, medium = 0.5, large = 0.8

Knee angular velocity + = extension, - = flexion, Hip Angular Velocity - = extension, + = flexion

5.2.2.1 Knee:

A significant main effect of gender was observed for knee angle at ball contact, with females demonstrating more extended knee angles than males (Table 6; $p = .009$). No significant gender effects were observed for minimum knee angle or knee angular velocities at support foot touchdown or peak flexion (all $p > .05$).

5.2.2.2 Hip:

A significant main effect of gender was observed for hip angle at support foot touchdown, with females demonstrating more flexed hip positions than males (Table 6; both $p = .009$). No significant gender effects were observed for hip angle at ball contact or for hip angular velocities at any phase of the kick (all $p = > .05$).

5.2.2.3 GRF:

No significant main effects of gender were observed for anterior–posterior ground reaction forces at ball contact or for maximal vertical ground reaction forces (Table 6; both $p > .05$).

5.3 Continuous:

Male vs female continuous data was not significant for knee angle (Figure 11). There was a main effect of speed on knee flexion-extension angle. Specifically, the fast approach kicks resulted in a smaller knee flexion-extension angle when compared with slow approach kicks for majority of the stance phase (14-100%, $t < 2.624$, $p < .001$. Figure 12).

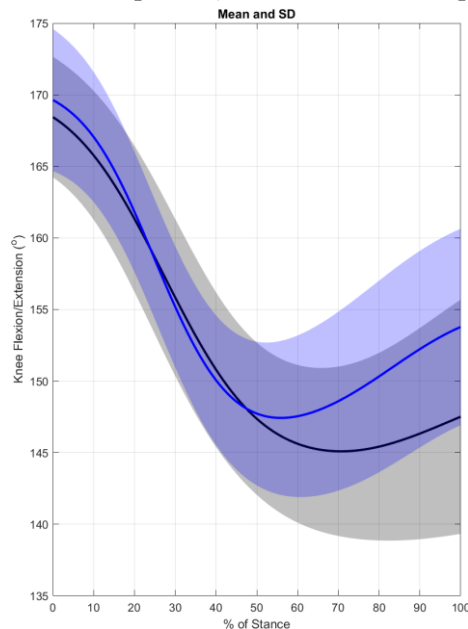


Figure 11: Knee Angle: Male (Black) vs Female (Blue)

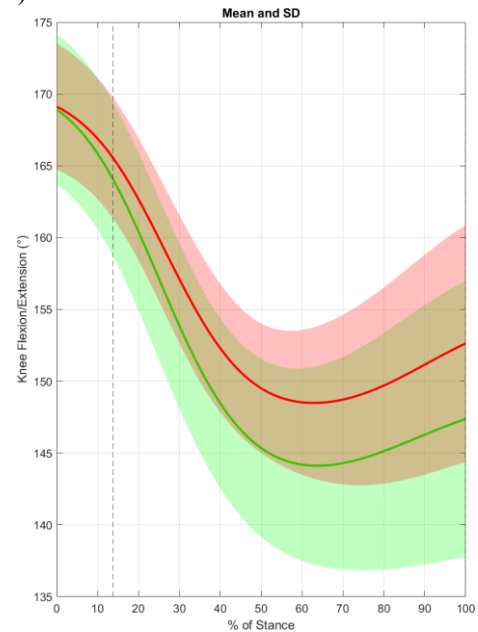


Figure 12: Knee Angle: Fast (Green) vs Slow (Red)

Female kickers exhibited greater knee flexion-extension angular velocity when compared with male kickers (47-79%, $t < 2.898$, $p = .002$. Figure 13). There was a main effect of speed on knee flexion-extension angular velocity. Specifically, the fast approach kicks resulted in a greater knee flexion angular velocity when compared with slow approach kicks for the first half of the stance phase (0-48%, $t < 2.909$, $p < .001$. Figure 14).

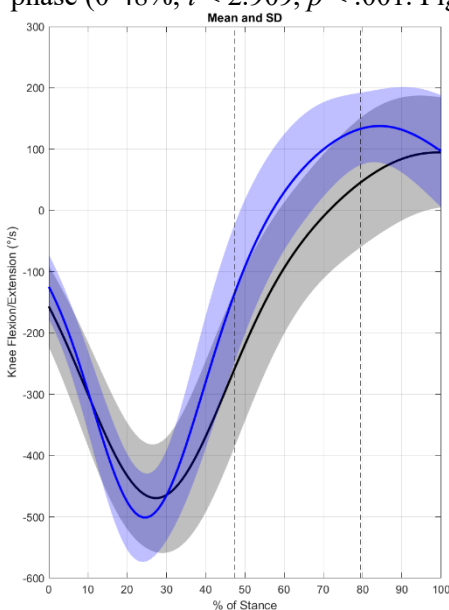


Figure 14: Knee Angular Velocity: Male (Black) vs Female (Blue)

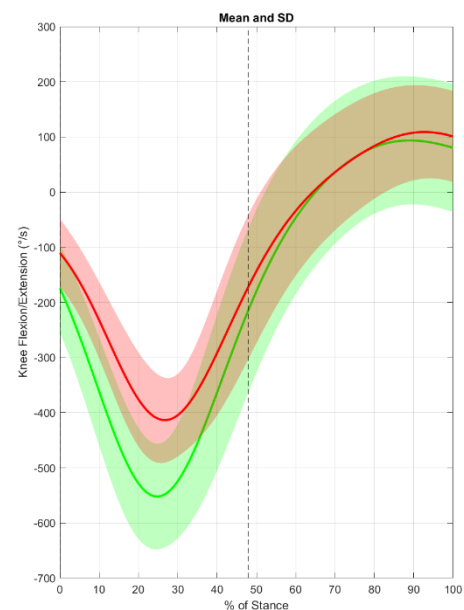


Figure 13: Knee Angular Velocity: Fast (Green) vs Slow (Red)

There was a main effect of gender on hip flexion-extension angle. Specifically, the male kickers exhibited greater hip extension angles when compared with female kickers for over half of the stance phase (0-58%, $t < 2.545$, $p .0143$. Figure 15). Fast approach kicks showed a greater hip extension angle when compared with slow approach kicks for entire of the stance phase (0-100%, $t < 2.656$, $p < .001$. Figure 16).

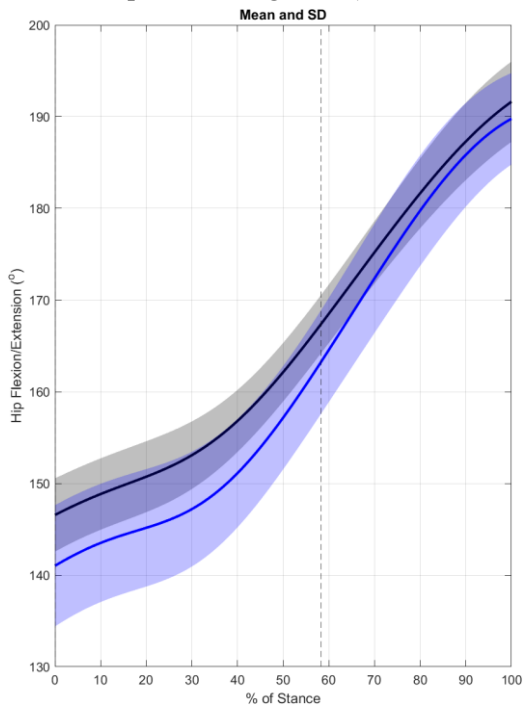


Figure 15: Hip Angle: Male (Black) vs Female (Blue)

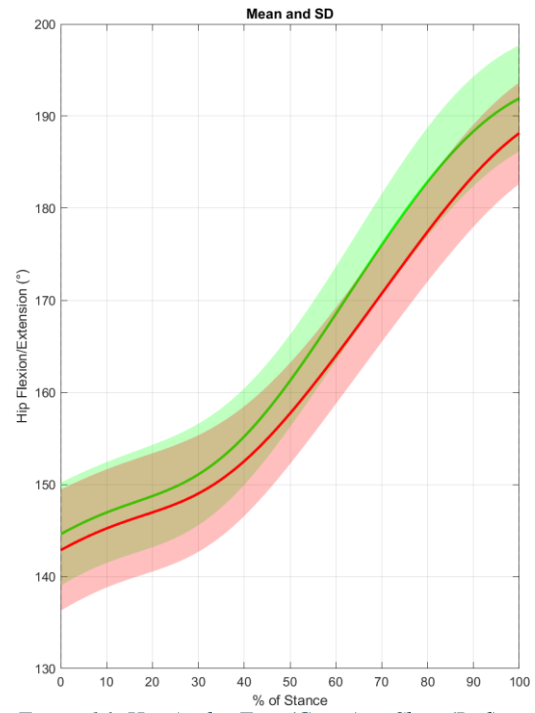


Figure 16: Hip Angle: Fast (Green) vs Slow (Red)

No significant main effect of gender on hip flexion-extension angular velocity was found (Figure 17). There was a main effect of speed on hip flexion-extension angular velocity. Specifically, the fast approach kicks resulted in a greater hip extension angular velocity when compared with slow approach kicks for majority of the stance phase (18-83%, $t < 2.965$, $p < .001$. Figure 18). Slow approach kicks also resulted in a greater hip extension angular velocity when compared with fast approach kicks during the final stages (95-100%, $t < 2.965$, $p < .043$. Figure 18).

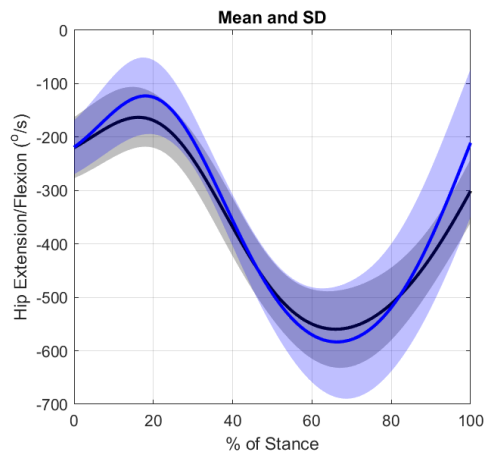


Figure 17: Hip Angular Velocity: Male (Black) vs Female (Blue)

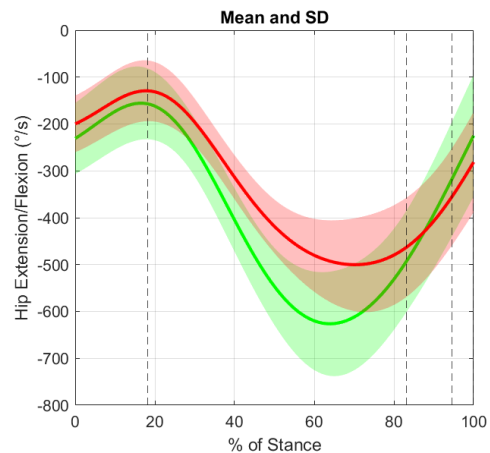


Figure 18: Hip Angular Velocity: Fast (Green) vs Slow (Red)

There was no main effect of gender on Z-GRF (figure 19). There was a main effect of speed on Z-GRF. Specifically, the fast approach kicks resulted in a greater Z-GRF when compared with slow approach kicks during the initial loading of the support leg (18-41%, $t < 3.840$, $p < .001$. Figure 20).

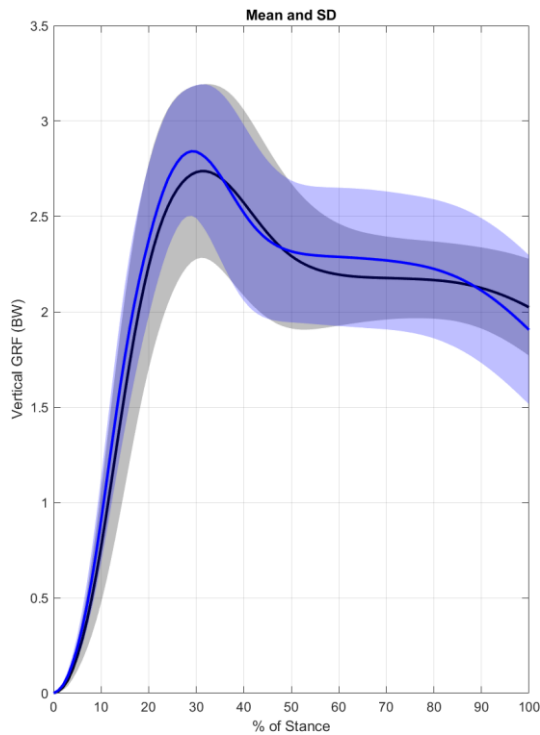


Figure 19: Vertical GRF: Male (Black) vs Female (Blue)

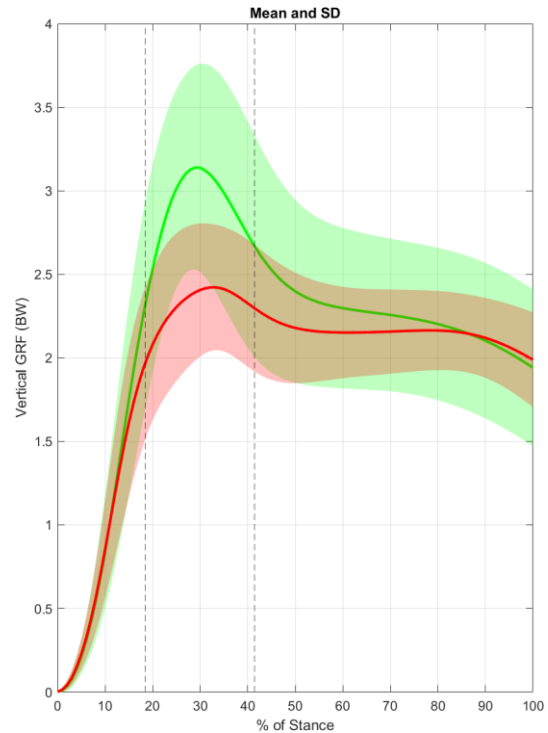


Figure 20: Vertical GRF: Fast (Green) vs Slow (Red)

There was a main effect of gender on Y-GRF. Specifically, female kickers resulted in a greater Y-GRF when compared with male kickers (23-67%, $t < 3.876$, $p < .001$. Figure 21). Fast approach kicks resulted in a greater Y-GRF when compared with slow approach kicks (8-29%, $t < 3.840$, $p < .001$. Figure 22). Later in the stance phase the slow approach kicks resulted in a greater Y-GRF when compared to fast approach kicks (67-100%, $t < 3.840$, $p < .001$. Figure 22).

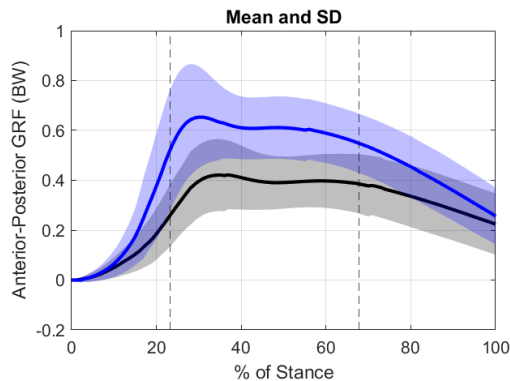


Figure 21: AP GRF: Male (Black) vs Female (Blue)

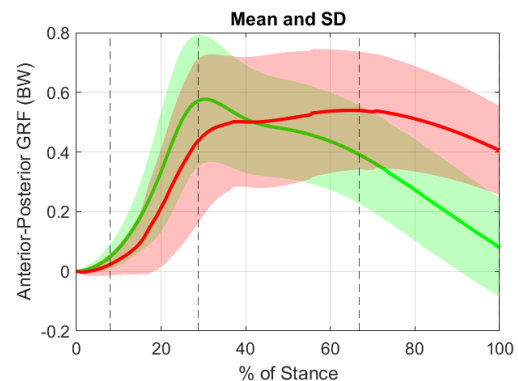


Figure 22: AP GRF: Fast (Green) vs Slow (Red)

6.0 Discussion

There were two aims in this study: to determine if support leg mechanics differed between a fast and slow approach speed, and if mechanics were different for male and female athletes. Both of these aims were addressed. Fast approach kicks were significantly different to slow approach kicks across all parameters. In contrast, male and female kickers were similar in majority of parameters, although differences were observed at key instants of the stance phase, specifically knee angle at ball contact and hip angle at support foot touchdown. These findings suggest that there may be specific training needed to be done to coach differences in support leg mechanics for fast and slow approach kicks, whilst males and females may need to be coached differently at stages of the stance phase.

6.1 Foot Speed, Ball Speed and Trajectory:

Foot and ball speeds differed between both approach speed and genders. The slower foot and ball speeds for females compared to males has been found in previous research (Cust et al., 2019) and so seems reasonable. However, an interesting difference occurred between the fast and slow approach kicks. Fast approach kicks were characterised by faster foot and ball speeds and significantly lower ball trajectories compared to slow approach kicks. This indicated that during the fast approach, kickers would propel the ball faster and at a lower angle. Importantly all kicks analysed hit the target so this might be a strategy given the different conditions at ball contact. Due to the faster approach, the ball itself will be moving faster towards the target. Hence to strike the ball with appropriate force, the foot needs to move faster. Given the faster ball speed, the trajectory would need to be lowered to ensure the ball hits the target and does not fly over the top of it. Alternatively, the strategy of the slower ball speeds exhibited by the slow-approach kicks was to increase the angle of trajectory to ensure the ball does not fall short of the target. This pattern was evident in both male and female kickers, with females having larger trajectories compared to males to account for the slower ball speed. This result highlights the need to train both slow and fast approach speed kicks.

6.2 Fast vs Slow:

When examining Table 5: Fast vs Slow, all 11 parameters were significantly different. This indicates that there is a need to examine for technical parameters when comparing kicks at fast approach speeds and kicks at slow approach speeds. Continuous data, shows that there are significant differences between fast and slow approach speed kicks, with all six parameters

indicating at least one section of significant difference between support foot touch down and ball contact.

6.2.1 Knee Kinematics:

The knee was extended (approximately 169°) at support-foot touchdown prior to any loading. Once there was loading on the knee it began to flex, until just after mid stance phase reaching approximately 145° , before extending prior to ball contact. This can be seen in the knee angles and angular velocities where from support foot touch down till mid stance phase, the knee is producing flexion velocity and then produces knee extension velocity prior to ball contact (Figure 14). Knee angles differed between fast and slow approach kicks. For the fast approach kicks, the knee had greater maximal flexion and remained more flexed through till ball contact compared to slow approach kicks. Further for knee angular velocities, fast approach kicks had greater knee flexion angular velocities at support foot touch down and then maximal flexion velocities, compared to slow approach kicks. Slow approach kicks had greater maximal extension velocity and greater extension velocity at ball contact.

The slow approach kicks exhibited greater knee extension at initial support foot touchdown ($152.7^\circ \pm 8.5$) compared to the fast approach kicks ($147.4^\circ \pm 9.8$) with a mean difference of 5.3° . During the slow approach kicks, athletes may have increased the final stride length to help gain slightly more momentum before kicking, leading to a more extended knee compared to fast approach kicks, where stride lengths would be determined by their speed, because as an individual increases their running speed, there is also an increase in stride length (Hamill et al., 1983). When examining the continuous data, it can be clearly seen that the slow approach kicks remain more extended, with significantly less flexion occurring during the stance phase (Figure 14). From 13.75% of the stance phase through till ball contact, there was a significant difference ($p < 0.001$), even though both speeds followed a similar pattern from support foot touchdown. Both fast and slow approach kicks started with similar knee extension at support foot touchdown, however, the rate of flexion is clearly different, with the fast approach kicks flexing at a greater rate, with a faster drop off compared to the slow approach kicks which seems more gradual. The faster kicks clearly had a greater max flexion, where fast approach kicks at a more flexed knee minimum angle (142.7°), compared to slow approach kicks where they were more extended (147.4°). These minimum knee angle differences may explain why there was also a difference in knee angle of a similar value ($\sim 5^\circ$) just after minimum knee angle occurs, which may be linked into having to absorb greater ground reaction forces to help stabilise the body, compared to the slow which had

a smaller max flexion. From examining the graph, it looks like both fast and slow go through a similar amount of extension right before ball contact, indicating similar knee angle strategies before ball contact. Similar findings have been reported, where it was also found that the slow approach speed kicks were performed with a more extended support leg to compensate for the lack of forward velocity compared to fast approach kicks (Augustus et al., 2021). It was also found that fast approach kicks tended to present with greater knee flexion to ensure CoM deceleration was optimal to be able to complete the kick. This might link what Inoue et al., (2014) stated about the support leg having two roles, regulate absorption of GRFs and ensure optimal CoM deceleration for a given kick. This ties into why slow approach kicks may be more extended than fast approach kicks as there is less GRFs to absorb and slower rate of which the CoM needs to decelerate at.

Knee angular velocities were significantly different between approach speeds. At ball contact, fast approach kicks had a greater knee flexion velocity ($-172.2^{\circ}/s$) compared to slow approach kicks ($-150.0^{\circ}/s$), indicating that fast approach kicks are required to help stabilise/absorb ground reaction forces instantly at impact, compared to slow approach kicks where there is a more gradual requirement for knee flexion to occur to create stability. Fast approach kicks also exhibited greater peak knee flexion velocity, $-577.5^{\circ}/s$, compared to slow approach kicks, $-440.5^{\circ}/s$. This shows that the fast approach kicks support leg limb needed to decelerate at a faster rate to help stabilise the body under the greater amounts of ground reaction forces that were created. When examining the continuous data, it can be seen that both slow and fast approach kicks don't have any knee extension velocity until the final third of the kicking phase, where they both start extending. This is supported by Inoue et al., (2014) who illustrated that the knee extensor groups work eccentrically up until the final phase of kicking. At ball contact, slow approach kicks have a non-significant greater knee extension velocity compared to fast approach kicks. This might be due to slow approach kicks needing to extend more to help promote a whole-body lift to help generate kick-leg foot speed to help generate the required distance as there was less momentum leading up to the kick.

6.2.2 Hip Kinematics:

At support foot touchdown the hip is slightly flexed and starts to slowly extend during the early stages of stance, which can be seen in the hip angular velocity graph (Figure 15) where the hip is extending at one of the slowest rates during stance phase. The hip then starts to extend at a much faster rate during majority of the stance phase reaching peak hip extension angular velocity just

after mid phase. After the peak, there is a reduction in hip extension velocity all the way through until ball contact. Even though there is a reduction in extension rates, both slow and fast approach kicks reach hyper extension in the hip reaching past 180° and still extending at a rate at ball contact.

At support foot touchdown, fast and slow approach kicks had a significantly different hip angle with a difference of 1.76° . After support foot touchdown during fast and slow approach kicks, the hip continued to extend throughout the kicking phase, with both types of kick following a similar pattern. At ball contact, fast approach kicks were more extended by 3.6° . Hip angular velocities had a similar pattern initially with both fast and slow having an angular velocity of approximately $200^\circ/\text{s}$ with the hip then decreasing extension velocity, before fast and slow increased extension velocity. Differences start to exist with differences in maximal hip extension velocity, fast approach kicks being greater than slower approach kicks, and differences in timing, fast approach kicks reached maximal extension velocity earlier in stance phase than slow approach kicks. Leading up to ball contact, both fast and slow had reductions in hip extension velocity, with fast approach kicks having a greater angular deceleration than slow approach kicks.

Hip angles differed significantly throughout the entire stance phase between fast approach kicks and slow approach kicks. At support foot touchdown, fast approach kicks adopted a more extended hip angle (144.5°) compared to slow approach kicks (142.7°). Both fast and slow approach kicks, extended throughout the entire stance phase with neither flexing at any stage. At ball contact, fast approach kicks were significantly more extended (191.9°) compared to slow (188.3°), which is also the maximal hip angle during the stance phase. Both fast and slow approach speed kicks demonstrated hip hyperextension, leading to an indication that centre of mass was in front of the hip joint by ball contact or the possible presence of leaning back in the kick, similar to what was found in the female vs male comparison.

Fast approach kicks had a significantly greater hip extension velocity compared to slow approach kicks, with a difference of $29.87^\circ/\text{s}$, indicating that players need to be able to extend their hip extensors at fast rates to be able to perform fast approach kicks on the run, compared to slow approach kicks, where the range of motion isn't as great, and hip extensors have more time to extend. At ball contact, slow approach kicks had greater hip extension velocity, indicating that slow approach kicks were extending at a greater rate at ball contact compared to fast approach kicks who had a far greater decrease in hip extension velocity leading to ball contact. Throughout

majority of the stance phase, fast approach kicks, had greater hip extension velocity, until the final 15% of the stance phase, where slow approach kicks had greater knee extension velocity.

6.2.3 Ground Reaction Forces

6.2.3.1 Z-GRF

After support foot touchdown, there is the loading phase where there is a rapid increase in vertical ground reaction forces created between the support leg and the ground. Peak vertical forces occurred at 30% of the stance phase where, and then there was a rapid reduction before the vertical forces plateaued or had minimal reductions in forces for majority of the stance phase after peak force. However, right before ball contact there were reductions in vertical forces in both fast and slow approach kicks.

Maximal vertical GRF (normalised to body weight) were found to have a significant difference between speeds. Fast speed had a higher average GRF ($3.47 \text{ BW} \pm 0.50$), compared to the slow speed ($2.68 \text{ BW} \pm 0.36$), indicating that when moving at a faster speed, a higher GRF is expected to occur. Speed is a significant effector on the magnitudes of impact forces. Which is in line with previous studies who examined impact and active peak forces over differing speeds (ranging from 3.35 – 4.47 m/s), as the speed went up so did the impact peak (Frederick & Hagy, 1986). The slowest speed of 3.35 m/s recorded an absolute impact peak of 1365 N, whilst the fast speed (4.47 m/s) recorded a greater average peak of 1963 N. This is in line with this study where the fast approach kicks had a significantly greater peak impact force compared to the slow speed. This is further supported by Hamill et al., (1983) who found that as speeds increase, so did maximal vertical ground reaction forces. And furthermore, it has been reported that as runners increase their speed, the more force they exerted on the ground producing greater external loads on their bodies (Jiang et al., 2024; Schache et al., 2014). When the approach speed increased in the trials, it was expected to see the vertical ground reaction forces increase based on what has been found in previous research on running at different speeds.

When moving at faster speeds, it is expected that there will be a larger impact force on the ground due to the higher momentum of the body's centre of gravity. A larger impact force in turn means greater forces for the joints to absorb during impact to help stabilise the body during the kicking phase. Being able to withstand these larger forces when moving at faster speeds, helps to prevent a collapse of the support leg and being able to stay upright which has been found to be important

during AFL kicking (Ball, 2013), as well as being able to maintain posture and balance. This is compared to the slow speed where there are significantly less forces needing to be absorbed and can be seen by the min knee angle that it is greater than that of the fast approach speed, as it flexes a greater amount to be able to absorb forces and remain balanced. A greater vertical force also can be indicative of the need to slow down the centre of gravity to a speed that will allow the athlete to be able to perform the kick efficiently and at their highest possible standard. Ball (2013) reported maximal vertical ground reaction forces of 3.0 BW where an approach speed of 3.38 m/s, slower than the fast approach speed, and faster than the slow approach speed. Ball projected that with a higher approach velocity, the maximum vertical GRF would approximately double, leading to potential load increases leading to injury. However, this was not evident within this study as max vertical GRFs remained similar to that of what was reported by Ball (2013).

These findings are greater than what has been reported within soccer trials, with GRFs being found to be in excess of two times body weight (Inoue et al., 2014, Kellis et al., 2004), whilst they have been reported to exceed three times body weight for the fast approach kicks. Inoue et al (2014), examined instep soccer kicks off a standardised 3 step run-up, similar to the slow approach kick protocol within this study. They demonstrated similar ground reaction force values to previous soccer trials. Inoue et al (2014) speculated that the support leg helps to resist large external force in order to stabilise the body, and to transfer the mechanical energy to the proximal segment, contributing to a proximal-distal sequential motion of the swing leg. These roles of the support leg may be similar during the slow approach kicks, and possibly during the fast approach kicks, as there is a higher need for the support leg to help stabilise the body during the kicking motion.

6.2.3.2 Y-GRF:

During the early stages of support leg loading, there is a rapid increase in braking forces to help the kicker slow down and stabilise for the kick. From approximately 30% of the stance phase, fast and slow approach kicks had differing patterns. Fast approach kicks started to decrease after reaching their peak in this early phase, with continual reductions in force all the way through to ball contact almost reaching zero posterior forces. Whilst slow approach kicks kept increasing, reaching their peak much later in the stance phase (approx. 75%). At ball contact slow approach kicks had significantly greater amount of posterior forces present.

Fast and slow approach kicks had very different patterns of Anterior-posterior ground reaction forces (AP-GRF) and peaked at different stage of the stance phase. Fast approach kicks AP GRFs peaked ~30% of the stance phase, whilst slow approach kicks peaked ~70% of stance phase. After the initial peak for fast approach kicks, the anterior/posterior forces started to decline, whilst the slow approach kick forces continued to increase throughout the stance phase till it reached the peak and slowly started to decline. AP-GRF at ball contact (BC) were found to be significant when comparing the two separate speeds (<0.001), however were not significant when comparing the different genders. When looking at the force vectors during different trials, it was clear to see that during the fast approach kicks, the athletes were more upright and leaning forward during the kick, compared to the slow approach kick where they were leaning back substantially more. Fast approach kicks at a posterior force of $0.093 \text{ BW} (\pm 0.172)$, compared to slow approach kicks having a posterior force of $0.405 \text{ BW} (\pm 0.151)$. This significant difference indicates that there were different technique approaches used to kick the ball the same distance under each condition. During the slow approach kicks, athletes leant further back to help get under the ball a bit more to help get a higher trajectory leading to the getting the distance that was required, compared to the fast approach kicks, where athletes may have used more of their momentum that they had gathered during their run-up to help get the distance required. Hamill et al (1983), stated that as an individual increases their running speed, so will their stride length. As a result, ground contact will be further behind COM resulting in a larger braking force. This which is not evident when examining AF kicking, with slow approach speed kicks creating larger braking forces compared to the fast approach kicks. Augustus (2021) found no significant differences between different speeds when examining braking force impulse. There were only small, reported differences of 2.7 Ns, which is similar to this study where there were no significant differences with maximal braking forces, only at ball contact and during different periods of the stance phase.

6.3 Male vs Female:

When comparing males and females there were only two significantly different parameters when looking at the discrete data (Table 6: Male vs Female). The parameters that were significantly different are: Knee angle at ball contact ($p = 0.009$), hip angle at support foot touchdown ($p = 0.009$).

The continuous data suggests that during the stance phase, males and females were significantly different during three different parameters: Knee angular velocity, hip angle, and braking forces.

6.3.1 Knee Kinematics:

Male and Female kickers landed with an extended knee of approximately 169° . During the loading phase, the knee began to flex with both genders reaching their maximal knee flexion during this stage. This is where differences in timings of maximal flexion and absolute angles begin with females reaching maximal knee flexion approximately 15% earlier in the stance phase, whilst males have a greater maximal flexion by approximately 3° . Both genders extend between maximal flexion and ball contact, where females were more extended by 7° . Further knee angular velocity of the knee, male kickers had greater flexion velocity at support foot touchdown, whilst female kickers had greater maximal knee flexion and extension velocity.

Female players exhibited a smaller maximal knee flexion (146.7°) compared to male AF players (143.5°), where 180° represents maximal knee extension, 0° represents maximal knee flexion. This indicates that females tend to stay slightly more upright/extended throughout the kicking phase and do not lower their centre of gravity as much as males. This finding is supported by Cust et al. (2019), who found that females had less knee flexion in preferred leg-kicks ($143 \pm 11^\circ$), compared to male knee angles found by Ball (2013) who reported average knee flexion at $137 \pm 6^\circ$. These corresponding results indicate that females will tend to have a more extended knee angle during the kick phase than males. This can also be seen when comparing males and females when moving at different speeds (Table 4: Discrete), where females continued to have a slightly more extended knee angle than males. This can also be seen when examining the continuous data, where females (blue), where extended majority of the stance phase, with males having greater knee extension for only 20% of the phase. This is due to females flexing at a faster rate than males, who had more gradual knee flexion however was flexing for a longer duration than females leading to greater knee flexion.

Males at SFTD, exhibited significantly greater knee flexion angular velocity ($-158^{\circ}/s$) compared to females ($-119.1^{\circ}/s$). However, females had a peak knee flexion velocity of $-522.3^{\circ}/s$, compared to males who achieved a lesser max knee flexion velocity ($-495.7^{\circ}/s$). With a greater knee flexion velocity, this meant that female kickers reached their maximal knee flexion angle earlier than males. As seen in Figure 12, where female athletes reached maximal knee flexion $\sim 50\%$ of stance phase, whilst males continued to flex, reaching maximal knee flexion at $\sim 70\%$ of the stance phase, considerably later than females. Even though females achieved a greater peak knee flexion velocity, males had a greater peak knee flexion angle, which is due to males flexing at higher velocity for longer compared to females who reached peak flexion velocity earlier, but then decreased their flexion velocity earlier. As seen in Figure 12, females reached knee extension velocity approximately 60% of the stance phase, indicating earlier knee extension than males who didn't reach extension velocity until approximately 80% of the stance phase. Even though females reached a greater peak extension velocity, females and males had a non-significant difference in knee angular velocities. This is an interesting finding as it indicates that females were unable to continue extending during the final and most important stage of the stance phase for kicking, ball contact. Having a more extended knee angle is believed to help create a whole-body lift (Augustus et al., 2017; Inoue et al., 2014), which helps to increase kick leg lever length and in turn kick foot velocity, which is a key indicator for kicking distance.

This different timing in gradual knee extension may have had an impact on knee angle at ball contact, where females had a significantly greater extended knee angle compared to males (153.9 vs 146.6 , $p = 0.009$). This might have been a strategy from the female players to try to generate a greater whole-body lift so that the kick leg may be more extended at ball contact, which is an area that could be examined in future research. Females extended more between their maximal knee flexion to ball contact (7.16°), compared to males who only extend on average 3.15° from maximal flexion to ball contact (min knee angle – ball contact). Ball (2013) found that having a more extended knee angle at ball contact was important in allowing maximal foot speed generation, due to the longer lever length available, which helps with kicking a further distance, which is required when kicking over $30\text{-}35\text{m}$. This difference may also be due to males being able to kick further than female athletes, who for some it may be a near maximal kick, kicking 35m , whereas for males, it may be a smaller percentage of their maximal kick, leading to males being able to have a more flexed support leg to kick the same distance. This comparison may need to be run, comparing similar percentage of maximal distance kicks. Elite male AF players can kick maximally up to $61\text{-}62\text{m}$ (Ball, 2008), however not all players in this study were elite level players. However, elite female AF tend to be able to kick $\sim 35\text{-}40\text{ m}$ on average (unpublished AFLW data). Future research may need to investigate comparing male and female AF players,

when kicking maximally instead of a set distance which may be a different percentage of maximal kicks.

Blair et al (2020), when reporting on goal kicking over 30m, with eight male participants, found that accurate kickers demonstrated a more extended knee at SFTD and remained more extended during the stance phase until ball contact. This supported what has been found previously in distance kicking (Ball 2013, Cust et al., 2019). Blair et al. (2020) reported knee angles of 142° at ball contact which is a more flexed knee angle than what was reported by both genders within in this study, with males reporting an average knee angle of 146.6° , whilst females had a significantly more extended angle of 153.9° at ball contact. Males only report a different of 4° in knee angle at ball contact between set shots and field kicking, whilst females were 11° difference. Whilst maximum support leg knee flexion was reported to be 137° by Blair et al, (2020), which was a greater amount of flexion than what was reported in this study, with females having a maximal knee flexion angle of 146.7° , and males having a more flexed knee of 143.5° . These differences may indicate that the knee angles differ when examining set shot goal kicking with a player in front of the kicker, compared to general field kicking where just hitting a clear target.

6.3.2 Hip Kinematics:

Male and females landed with their hip in maximal flexion at support foot touchdown (approximately 145°). Females had a more flexed hip angle throughout the entire stance phase compared to males and the angles were significantly different during most of the stance phase (0-58%). From support foot touchdown through to ball contact, both continued to extend following the same pattern throughout the stance phase, leading to maximum hip angle at ball contact (approximately 190°). Males and females once again followed a similar pattern for hip angular velocities where they both decreased hip extension angular velocity after support foot touchdown, with females having less extension velocity during this period. The angular velocities then increased leading to females having a greater maximal hip extension velocity ($-604.9^\circ/\text{s}$) compared to males ($-553.6^\circ/\text{s}$), and then at ball contact, both velocities decreased, where females had smaller hip extension velocity.

At support foot touchdown, females adopted a lower body position more than males, with females having a hip angle of 141.0° compared to males 146.2° . This indicates that females tend to flex at the hips slightly more to lower their centre of mass, compared to males who seemed to flex at the knee to lower their body. This means that there is likely a greater eccentric load on the hip

extensors for females to be able to control the hip angle during this motion. This is greater amount of flexion than what was found by Blair et al., (2020) who reported hip angles in males at 150° when examining set shot goal kicking over 30m. Meanwhile Dicheria et al., (2006) found the support leg hip to have an angle of 131° when performing kicks over 15m. The findings in this study relate more to those of Blair et al. (2020), 30m, and may indicate that their findings may be more relevant than those of Dicheria et al. (2006), 15m, when examining kicking mechanics at support foot touchdown. At ball contact, females were similar (189.9°) compared to males (190.3°), which was a small insignificant finding. Both males and females presented with hyperextension at ball contact indicating that either the centre of mass has moved past the support leg, leading to hyperextension or the athletes are leaning back slightly on the kick, extending the hip angle. This was observed during the trials and when doing visual inspections during the analysis of kickers. Both Blair (2020) and Dicheria (2006) reported findings that the hip was still flexed at ball contact by 15 and 7.7° respectively, rather than the slight extension of the hip that was found in this study. This may indicate that at ball contact, there are differences in hip mechanics when kicking for goal, over 15m or on the run kicking 35m.

The flexion-extension angular velocity of the hip was not significantly different between male and females, where similar patterns were had throughout the entire stance phase by both genders. As seen in figure 18, the angular velocity remained in extension throughout the entire stance phase. Under initial loading of the support leg, both genders reached approximately $-150^{\circ}/s$ of hip angular velocity, however, between 18-83% of the stance phase, the angular velocities were significantly different, where females reached a greater hip extension angular velocity compared to males (-604.9 Vs $-553.6^{\circ}/s$). In the final stages of the stance phase (95-100%), males had a significantly greater hip extension velocity compared to females. Having a greater hip extension angular velocity during this phase prior to ball contact, as hip angular velocity at ball contact impacts the kick leg foot speed, that can be generated through momentum being transferred from the support leg to the kick leg (Atack & Bezodis, 2023).

6.3.3 Ground Reaction Forces

6.3.3.1 Vertical GRF:

The vertical ground reactions exponentially increased after support foot touchdown as the support leg goes through loading. Both males and females increased at a similar rate, with both genders reaching their peak early in the stance phase. After the initial loading, both decreased as mid stance phase was reached, before plateauing for majority of the stance phase. Males and females

had similar patterns throughout the stance phase, with no significant differences as seen in Figure 19.

Females exhibited a slightly greater maximal vertical GRF (3.14 BW) compared to males (3.02 BW) ($p = .363$). Females peaked earlier in the stance phase than males. This is similar to previous finding by Ball (2013), who found that elite males AFL players produced maximum vertical GRF of 3.0 BW. Due to there not being any female ground reaction force data within AF, there is a need to look at other kicking sports. The vertical ground reaction forces recorded in this study are larger than what has been reported for soccer by Orloff et al (2008), who reported peak vertical ground reaction forces of 2.28 BW for males and 2.42 BW for females. It has been reported that there were no significant differences between males and females which aligns with this present study where vertical ground reaction forces were a non-significant finding (Orloff et al., 2008). This indicates that females and males tend to put the same relative load through their support leg during the kicking motion. The forces reported in this study are also higher than what was found by Katis and Kelis (2004), who reported maximal vertical ground reaction forces of approximately 2.5 BW for males when completing a soccer instep kick.

The vertical ground reaction force continuous data shows that both genders followed a similar pattern and reached similar peaks, however the timings were slightly different, starting with different peak times. Females peaked at approximately 29% of stance phase, whilst males had peak vertical GRF at ~32% of stance phase. This is a very minor difference in timing of peak vertical forces. However, females having a slightly greater peak vertical force compared to males is an interesting finding, as it would be expected that males would be producing greater forces, due to increased speeds reached. With a similar pattern and non-significant values throughout the kick, this means that similar training patterns to withstand vertical forces under the same conditions, as both genders produce similar amounts of GRFs throughout the entire stance phase (Figure 18).

6.3.3.2 Anterior-Posterior GRF:

Braking forces between males and females had a similar pattern, however females had greater values throughout the stance phase relative to body weight. Both increased during the loading phase of the kick, where both genders reached their peak braking forces approximately 30% of the stance phase. Both then continued to steadily decline throughout the stance phase through till ball contact.

Females produced significantly greater anterior posterior forces than males for majority of the stance phase, reaching 0.78 BW compared to males 0.54 BW. This indicates that females use greater braking forces after support foot touchdown, to help slow down and remain balanced compared to males. These findings are less than what has been reported previously by Ball (2013), who reported maximal braking forces of up to 1.0 BW for male kickers. This is an interesting finding as Ball examined players completing kicks with approach speed run ups similar to slow speeds within this testing but had nearly double the braking forces than was found at fast speeds. This may indicate that the faster the athlete is moving at, the less braking forces are produced. Instead, it may be possible that the momentum carries the athlete through the stance phase and doesn't allow the support leg to create braking forces to help stabilise the athlete for the kick. A key difference between Ball's 2013 study and the current study may be the kicking distances, where Ball (2013) had athletes kicking maximally whilst in this study participants were only required to kick 35m. This may need to be examined in future research, if kicking distances lead to different braking forces being created.

Females continued to produce significantly more amounts of braking forces than males until 68% of the stance phase, after which braking forces decreased (Figure 19). Besides having greater braking forces, this may also be an indication that females may tend to lean back greater throughout the stance phase to help generate distance compared to males who may be more upright throughout the kick. At ball contact, females (.270) were still generating greater amounts of braking forces, it is no longer a significantly different amount to males (.230). However, it may indicate that posterior forces are beneficial for assisting in developing greater kick leg speed or for stabilizing the kicking movement (Ball, 2011). This is supported by Jiang (2024) who reported that females at slower speed had greater posterior forces than males when comparing ground reaction forces of male and female runners, which can be seen in Table 6 and Figure 20 where females maintain greater amount of posterior forces than men throughout the stance phase and at ball contact.

7.0 Limitations

A general limitation is this study was completed within a lab environment rather than completing it on an AF ground where players may be more comfortable to completing the tasks involved with this study. However, there were numerous delimiting factors that were put in place to reduce the impact of completing it in the lab space. One of the key factors was the usage of artificial turf in which all kicks and run-ups were completed on, to help replicate the grass surface in which AF games are played on. Also of note, most of the athletes in this study are familiar with kicking on artificial turf as there are facilities at most clubs for this to happen indoors. There are also a number of synthetic AF grounds around Australia. By using the artificial turf, this allowed the athletes to wear their football boots rather than runners which allowed them to kick in footwear that they are comfortable and kick regularly in. This was as opposed to using runners that would have needed to be worn if the testing was just completed on the mondo flooring, which is suitable surface for the football boots to be worn. All kicks were completed with game sized balls for male and female participants. All players also went through familiarisation kicks within the testing space, with testing only starting once they said they were comfortable within the lab. Making sure they were comfortable and used to the testing space was important to make sure that their kicks were natural and were like they would complete within a game.

8.0 Practical Implications

This study aimed to highlight how support leg mechanics may change during when moving at different approach speeds and identify if there were any differences between males and females. By identifying differences in technique at different speeds and between genders, suggestions can be made for coaching to potentially enhance player performance, and strength training to help with injury prevention.

8.1 Coaching:

During the slow approach kicks, there were significantly greater posterior forces which has an impact on the players ability to produce faster kick foot speeds. This in-turn impacts kicking distance as foot speed and kicking distance are related. Posterior forces may also have an impact on the trajectory angle of the kick with slow approach kicks generating greater hang time- this impacts ability to move ball efficiently across the ground. To help reduce posterior forces, coaches may encourage players to:

- Maintaining head position over the top of ball drop, as this will lead to players maintaining a more upright position. Typically, once the head goes back so will the rest of the trunk/body leading to posterior forces.
- Reduce time on the heel of the foot and encourage kickers to get up onto the ball of their foot.

By reducing posterior forces, this will also reduce the trajectory angle, helping kicks reach their desired destination faster rather than being in the air longer, which will help with enhancing quick all movement.

Numerous differences have been identified between slow and fast approach speed kicks, indicating a need for them to be coached to highlight technical differences. The following are key takeaways:

- Fast approach kicks have a more extended knee and hip angles throughout the kicking phase, indicating possible triple extension compared to slow approach kicks.
- During fast approach kicks players will be upright and more on the ball of their foot compared to slow approach kicks kicking more on the heel.

With these significant differences, it is clear that fast and slow constraint kicks need to be coached separately, within different training scenarios to allow players to learn the support-leg technique that may help player performance. This will also allow for large number of repetition and allow for specific coaching to take place.

At different stages of the kick phase, there were gender differences between the knee and hip kinematics. At support foot touchdown, females had greater hip flexion compared to males, whilst at ball contact females had a more extended knee. This indicates that for females their technique is to keep a straighter knee and bend at the hip more, whilst males tend to bend at the knee whilst stay more upright at the hip. This may indicate that females have a slightly different stance leg technique to male and therefore may need to be coached slightly differently. Alternatively, determining if this difference is strength based rather than movement based would mean a greater focus on conditioning of the support leg for females would be recommended.

8.2 Strength Training:

Results show several strength and conditioning training interventions that may reduce risk of injury and improve athlete performance, specifically when examining the angular velocities and ground reaction forces.

A general strength training suggestion is to improve core and hip strength, as this will help the kicker remain more upright during the kick, and therefore possibly reducing the posterior forces and be training method to help if there is a need to change female support leg strategy to more knee dominated. By training kickers to reduce posterior forces during later stages of the kick, this will also help with preventing lower back pain, where the repetition of excessive lumbar extension and force causes lower back pain (Tojima & Torii, 2018). Reducing the GRFs for female kickers late in the kicking phase may not only enhance player performance but also reduce risk of injury.

When athletes were kicking with faster approach speeds, there was a significantly larger amount of vertical ground reaction forces produced. Given from stance foot landing to minimum knee angle, the knee flexed 20-23 degrees during a phase of high GRF, the need for knee extensor eccentric strength to be able to manage and withstand such high loads through the leg will be important. This will allow kickers to delay max knee flexion, leading to a delayed extension velocity for later in the kicking phase, leading to a more extended support-leg position to be maintained which may help kickers attain a stronger base of support (Blair, 2020; Ball, 2013). Eccentric and isometric quadricap training can be completed to help facilitate this, whilst also helping to train female kickers to adopt a more knee dominant stance strategy if this is found to be more beneficial for kicking performance. For athletes that already adopt a more knee focused support limb, i.e. males, eccentric and isometric training can be considered.

A further consideration that can be considered is improving hip extensor strength and power during the late stages of the stance phase. This can be classified as a lesser consideration at hip angular velocities weren't significantly different at ball contact, however, the significant decrease females showed in hip extension velocity prior to ball contact was an interesting finding as hip angular velocity at ball contact impacts the kick leg foot speed that can be generated, as this allows the momentum generated by the support leg to transfer to the kick leg (Atack & Bezodis, 2023). This is training that can be done for males and females to enhance the transfer of momentum and reduce a decrease prior to ball contact.

9.0 Future Directions

Clear differences in kinematics and ground reaction forces have been found in this thesis. Expanding this to a kinetic analysis is an important next step. This will enable a better understanding of the muscular requirements (i.e. eccentric/concentric) and the level of joint moments that are existing in the support leg, similar to future work recommendation by Ball (2013). Given the different force profiles, as well as both the knee and hip working in different ranges for the different speeds and genders, understanding these factors will be useful for coaching and conditioning. It will also assist in informing a more comprehensive understanding of the movement from a biomechanical perspective.

Connecting the support and kick leg and examining how kick foot speed is generated would be a useful exploration from a theoretical point of view, as well as for coaching and conditioning insights. Even though the support leg plays an integral role in kicking performance as indicated by this thesis, connecting the technical aspects of it with the kick leg is important to evaluate, as this will help to better understand muscular demands during differing kicks, as well as coaching cues that can help with player performance when needing to complete skills at different speeds. It might also provide for a better comparison between male and female kickers to explore the strategies used to develop foot speed.

Previous studies have reported that the support leg helps to generate a whole-body lift to allow a longer kick leg lever length (Augustus et al., 2021) to help generate faster foot speeds and faster foot speeds have been found to be associated with further kicking distances (Ball, 2008). It was not within the scope of this masters study to examine the lift in which the support leg helps to generate, however, further studies could examine hip heights in different kicks and between genders to see the ability of the support leg to help create a whole-body lift and seeing the impact it has on foot speeds within AF kicking. It would also be of importance to understand if it is the lift or simply increased height of the hip that is the most relevant technical feature.

Further, this study only examined athletes kicking at a set distance, which may be differing percentages of maximal distances for males and females, as data shows that males are able to on average kick greater distances than females. Having both genders kick maximally or at a similar distance to their maximal distance, may give a broader indication as to whether techniques are similar or differing when kicking maximally as in this study males may not have needed to use

similar support leg mechanics to if they were kicking maximally. This can also tie in with examining whole-body lift, and see what mechanics are used at the support leg during these kicks. This may lead into interventions looking to help achieve greater kicking distances, through wanting to promote greater support leg action, an intervention recommended by Atack & Bezodis (2023) when examining female rugby place kicking differences to men.

Another future direction that may need to be explored is the cause of the hip hyperextension in the different kicks. Is it from the centre of mass of the athletes being in front of the support leg, leading to more extended hip angle, or is it due to the athletes leaning a back during the kick, leading to the trunk being displaced posteriorly to neutral positioning, causing a greater hip angle. Defining this in more detail has relevance to coaching and conditioning of the kick.

Examining if different kicking distances may lead to different posterior/braking forces can be another future research direction. As in this study, when kicking over 35m, the braking forces differed to Ball (2013), who examined braking forces in maximal kicks, where the differences were nearly doubled in Ball's study, so more research into the braking forces and requirements over distances may be important to look at.

With this study being completed with athletes kicking on artificial turf in a lab, a future direction may be to complete kicks outside of a lab based environment and test in the field, as this will allow for a wider range of kicks to be examined rather than drop punts and straight line movements. Examining the different kicks and angles at which players may take prior to the kick would allow for further understanding of mechanics beyond just the drop-punt.

10.0 Conclusion

This study evaluated the kinematics and kinetics of the support leg during AF kicking performed at different approach speeds, whilst also examining whether support leg mechanics differ between male and female athletes. Specifically, this study analysed knee and hip angles, angular velocities, and vertical and anterior-posterior ground reaction forces between support foot touchdown and ball contact. This study aimed to continue to develop the understanding of the role of the support leg in AF kicking, which needs to be continued to be researched.

The findings in this study indicate that approach speed has a substantial effect on support leg mechanics. All discrete and continuous measures were significantly different indicating that as speed increases, the loading and demands of the support leg changes. Fast approach kicks were characterised by greater knee flexion, greater hip extension and greater vertical force patterns when compared to slow approach kicks. These indicate that the support leg plays a more integral role to accommodate greater dynamic loading whilst providing stability and facilitating energy transfer to the kick leg. Therefore, the support leg not only acts as a braking mechanism for fast approach speed run-ups but also plays a critical role in managing athletes' momentum. With the large number of statistically different parameters examined, it is clear there is no 'optimal' kicking technique for kicking with a task constraint of movement speed, being a large influencer on support-leg dynamics. This will mean different coaching will need to be completed to the different support-leg techniques can be coached effectively.

Gender related differences were also identified, although there were fewer than what was found when examining approach speed differences. Male and females differed only in knee angle at ball contact and hip angle at support foot touchdown for discrete measures, whilst have differences in three continuous measures as well. Males had a more flexed knee angle at ball contact, and more extended hip angle, indicating the males preferred to extend at the hip, whilst females preferred to extend at the knee. These differences between males and females indicate that there may be different movement strategies for the genders at key stages of the kicking phase. The differences indicate that there may be a need to train different genders with slightly different coaching cues, rather than just having one 'optimal' technique that might not be achievable by both genders.

The findings in this study have practical implications for coaching, training, and injury prevention. The significant differences between fast and slow approach kicks, indicate that these

kicks could be coached as separate skills with focuses on the differing support leg mechanics and with training sessions aiming to include both fast and slow approach kicks. Additionally, the differences identified between males and females, suggest coaching specific knee and hip dynamics at ball contact and support foot touchdown may be important rather than just going with one technique for both genders. Further, for strength and conditioning coaching, the results indicate the importance of support leg strength to be able to tolerate high loads, especially during the fast approach speed kicks. Knee extensor eccentric strength, eccentric and isometric quadriceps training, hip extensor strength and power are all areas that will likely assist in this training. Improving these may assist in athletes managing support leg loading, improve performance and reduce the risk of injury.

Future research should examine the kinetics of support leg mechanics during maximal kicking. Given different ground reaction forces were found, and different knee and hip ranges were used for the different approach speeds, it would be useful to evaluate the concentric/eccentric differences to better inform conditioning of the support leg. Examining the kick leg at different approach speeds alone and in combination would enable a better understanding of transfer of momentum and performance differences. Differences between male and female kick leg may be another point of interest, particularly in how each gender develops kick foot speed through the kicking sequence.

Overall, this study offers insight into the loading and performance of the support leg at different approach speeds in Australian Football kicking, and highlighting differences between male and females, providing potential coaching and strength/injury prevention training to potentially enhance player performance.

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Appendices:

Appendix A: Velocity Parameters: Net vs Outdoor Kicking

Parameter	Net	Outdoors	Significance (<i>p</i>)
Approach Speed (m/s)	3.9 (± 1.26)	3.9 (± 1.17)	1.00
Foot Speed (m/s)	20.4 (±2.06)	20.6 (±2.02)	0.76
Ball Speed (m/s)	22.7 (± 1.71)	22.6 (± 2.22)	0.79
Trajectory Angle (°)	23.5 (±5.07)	27.1 (±3.92)	<0.001